

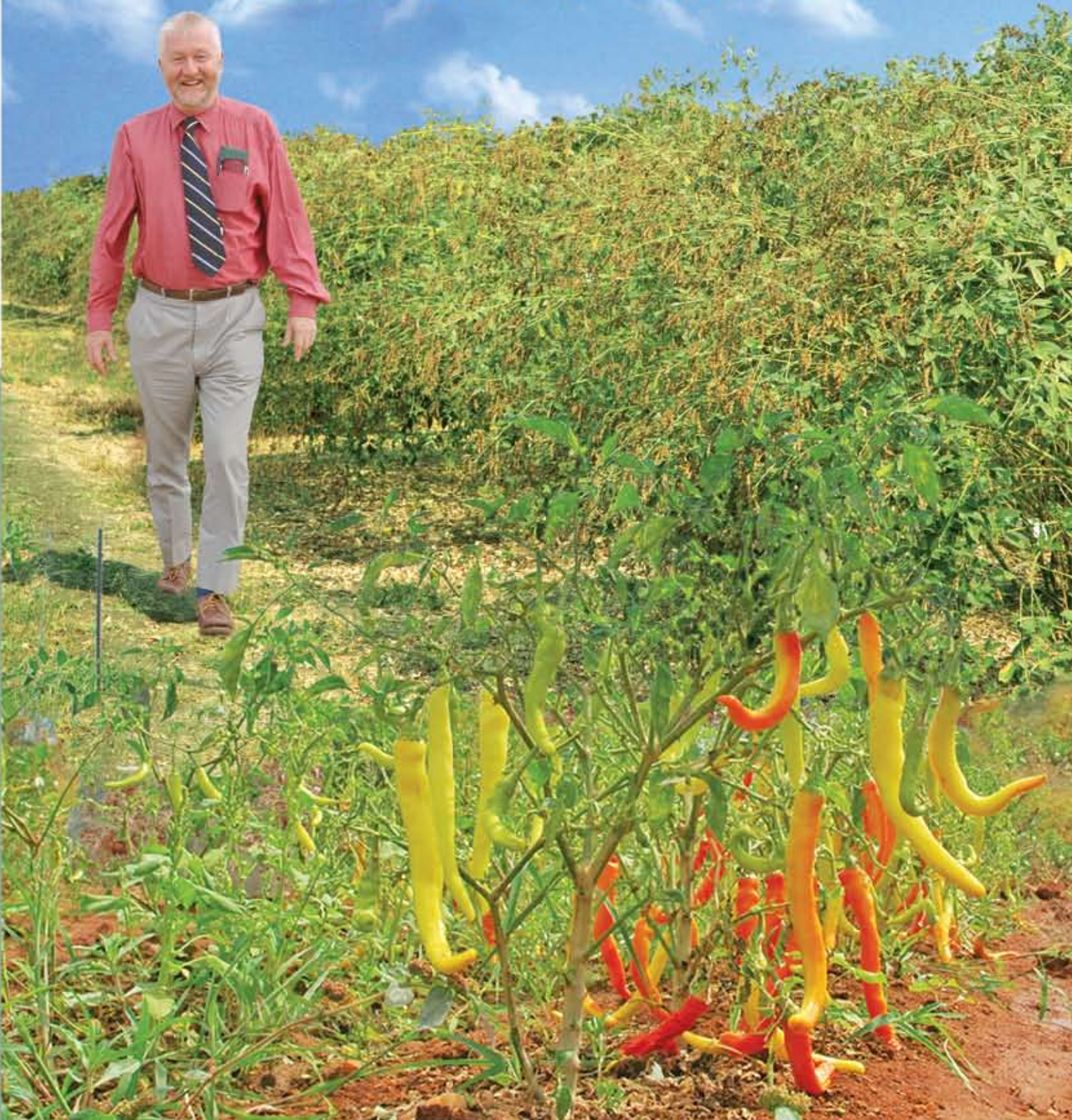


International Crops Research Institute for the Semi-Arid Tropics



# **ICRISAT Archival Report 2007**

*The Productivity and Livelihoods of  
Success in the SAT Nourished*





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# **ICRISAT Archival Report 2007**

## **The Productivity and Livelihoods of Success in the SAT Nourished**



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# ICRISAT Archival Report 2007

## The Productivity and Livelihoods of Success in the SAT Nourished

### Project 1

#### Improving policies and facilitating institutional innovation, markets and impact to support the sustained reduction of poverty and hunger in the SAT

**System Priority 5: Improving policies and facilitating institutional innovation to support sustainable reduction of poverty and hunger**

Priority 5 A: Science and Technology Policies and Institutions

Priority 5A, Specific goal 3: Improving incentives for technology generation, access and use

Priority 5A, Specific goal 5: Enhancing the structure, conduct and performance of knowledge-intensive institutions

**Output 1A: Best innovative practices and mechanisms for harmonization and utilization of seed-related and biosafety regulations and policies suitable for the specific conditions of the SAT piloted, promoted and adopted with new knowledge shared with partners**

*MTP Output Target 2007 1.1.1*

*Mechanisms for enhancing the utilization of market and non-market based exchange of germplasm through harmonization of seed policies developed and piloted in Africa;*

*MTP Output Target 2007 1.1.2*

*Innovative public-private partnerships and foundation seed enterprises to strengthen seed supply systems developed and piloted in Africa*

#### **1. A.1 Regional seed systems policy development (ESA)**

Project Rationale: Implementation of harmonized agreements across the 14 countries of SADC will enable smooth flow of improved seed across national boundaries at least cost through rationalization and harmonization of variety release systems; ii) seed certification system and; iii) phytosanitary regulations for seed systems.. This process will further facilitate increased access and wider choices of seeds to farmers and will consequently lead to increased productivity and income to farmers. This effort bodes well with the MTP outputs in Project 1 on “Improving policies and institutional innovations, markets and impact to support the sustained reduction of poverty and hunger.

The motivation from ICRISAT’s perspective arises from the concerns about the limited adoption of improved sorghum and pearl millet varieties in southern Africa. This led to the initiation of a series of studies on national and regional seed systems starting about 10 years ago. There is strong pressure from commercial seed companies for the development and implementation of harmonized rules and regulations to facilitate seed trade across national borders

Approach and methodology: This project is a continuation of a collaborative work initiated under USAID funding. ICRISAT is collaborating with Iowa State University and the SADC Seed Security Network (SSSN). The International Institute of Tropical Agriculture (IITA) is also a collaborator in the sense that funding for the project is passed through IITA. The second year funding was passed through IITA. In collaboration with the aforementioned partners as well as NARS of the 14 countries, the project has been working on three seed initiatives aimed at harmonization of seed trade that are different but seemingly interrelated.

The approach has basically been through implementation of a number of procedures—

- strategic studies focusing on how certain procedures are carried out with public and private sectors
- facilitating dialogue –private and public sector to debate and agree on least cost but scientifically
- acceptable procedures in creating a vibrant seed industry
- capacity building in strategic areas to enhance the skills of sub-sector participants

**Milestones:** Ministers responsible for Food, Agriculture and Natural Resources met in Lusaka, Zambia on 29 June 2007 to review progress of the sector. Eleven SADC Member States attended the meeting and these included Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe. Also in attendance at this meeting were representatives of the New Partnership for Africa's Development (NEPAD) and the Common Market for Eastern and Southern Africa (COMESA). A meeting of senior officials preceded the meeting. The Ministers reviewed the status of implementation of the seed trade policies harmonization aimed at creating a common seed system for the region and approved the three technical documents that had been prepared by the Southern Africa Seed Development Initiative, namely: i) SADC Variety Release System; ii) SADC Seed Certification System and; iii) SADC Phytosanitary for Seed Systems.

They noted that the harmonization will enable the seed system to increase the number of varieties available to farmers, promote investment and trade in the seed sector, and make it easier and cheaper for seed companies to introduce varieties in other Member States. This was a major achievement of a two-year work by ICRISAT and its partners.

**Major findings:** In addition to the above remarkable achievements, the project worked on the following key activities and made some significant achievements which will go a long way in supporting implementation of the seed policies harmonization agreements--

- Establishment of fully operational website for basic information on seed regulation and regulatory procedures
- Establishment of regional variety catalogue
- Promoting national acceptance of a regional plant breeders' rights agreement
- Fostering the establishment of a foundation seed unit
- Establish a baseline for evaluating the impact of regulatory harmonization on seed trade costs and the volume of seed traded
- Assessing the impact of relief seed on seed sector development

**Partners:**

The Seed Science Center, Iowa State University  
SADC Seed Security Unit  
COMESA  
ECOWAS/WAEMU/CILSS  
PAAP/ASARECA

**Publications:**

**SADC-SSN (Southern African Development Community Seed Security Network).** 2007. Harmonization agreements in variety evaluation and release; seed certification and phytosanitary regulations. SAD Secretariat, Gaborone, Botswana.

**SADC-SSN (Southern African Development Community Seed Security Network).** 2007. Seed Update. 1 (26). Gaborone, Botswana.

**Eastern and Southern Africa Seed Alliance:** Project Brief: ICRISAT; Iowa State University Seed Center and CNFA, Inc August, 2007

***1. A.2 The economics of biotechnology (GMOs) and the need for a regional policy: The case for COMESA countries (ESA)***

**Project Rationale:** Many countries in the world have adopted genetically modified organisms (GMOs) as products that can have great beneficial impact on agriculture, industry and trade. Since, Africa remains the only place in the world where food consumption per capita is declining, adoption of GM crops there is an option for increasing in farm-level productivity, food security and incomes for smallholder farmers. This activity sought to

(1) to estimate the impacts of GMO crops on farm incomes for maize and cotton, (2) to estimate the possible commercial exports risks associated with planting of GMO crops in the COMESA region, and (3) to summarize the developments to date in developing a regional policy on GMOs for COMESA countries. The activity is meant to contribute positively to the policy debate in adopting GMOs, which is critical as one of the options for pulling a large number of smallholder farmers out of poverty.

Methodology: Drawing on data derived from studies conducted between 2004 and 2006, by the Common Market for Eastern and Southern Africa (COMESA) in collaboration with a number of partners this activity sought to:

- Estimate the Potential Farm Income Gains from Bt maize and Bt cotton
  - Determination of the actual harvested area of maize/cotton in each case study country
  - Estimate the share of the maize/cotton area currently planted to improved varieties of maize/cotton, including hybrids and improved openly pollinated varieties (OPVs) for the sake of maize. This is assumed to be the area currently planted to improved varieties that will first switch to Bt. We assume here that where stalk borers/boll worms are a primary farm production and farm income constraint for these farmers, roughly 40 percent of the maize/cotton area currently planted to improved varieties will switch to Bt varieties within 5-10 years.
  - Adoption of evidence of net income gains per hectare recorded in other countries from switching to Bt—US \$25 per ha and US \$ 50 per ha for maize and cotton, respectively.
- Estimate Export Risk from Planting GMOs
- Export values of these commodities to various destinations were used to calculate potential risks under different scenarios. In order to compute the magnitude of risk, the export values are expressed as a percentage of total agricultural exports to the same destination. A value greater than 2% has been used in all cases as a measure of risk exposure.

#### Milestones and Major Findings:

Net Farm Incomes: Based on estimated proportion of current maize and cotton area likely to switch to GMO varieties in the six countries, the study showed the net income farmers might vary from US \$ 2.5 to 7.5 million for maize and from US \$ 0.05 to US \$ 9.5 million for cotton, across the six case study countries.

Export Risks: Egypt is the only country in the study that is likely to face significant decline (4%) in agricultural export, following the planting of GMOs. The other five countries would see their exports decline by not more than one percent (Table 2). More so, agricultural crops commonly exported to Europe are not at risk because they are not grown for commercial marketing in GMO form anywhere in the world.

Planting of GM-crops is an option for increased productivity, food security and incomes for smallholder farmers in Africa. Commercial export risks to Europe emanating from production and exports of GM crops are negligible. In fact, countries of the region should be more concerned with having a harmonized regional policy on GMOs because intra-regional exports on the available GM crops are larger compared with exports to Europe.

#### Publications:

**Minde IJ** and **Mazvimavi K.** 2007. The economics of biotechnology (GMOs) and the need for a regional policy: The case for COMESA countries. Paper presented at the 2nd African Agricultural Economics Conference, 20-22 August 2007, Accra, Ghana.

### ***1. A.3 Innovative approaches for generation and utilization of new agricultural technologies and for facilitating innovation identified and piloted***

Rationale: In most African countries there are poorly-developed mechanisms for the commercialization of publicly-developed varieties with the result that public research investments in plant breeding are not widely disseminated. Hence, the bulk of research investments made in crop breeding are from the public sector as opposed to commercial seed companies. The implementation of structural adjustment programs over the last two decades or so has resulted in most African governments privatizing their parastatal seed companies that were previously charged with marketing improved seed of publicly-developed varieties. Although there are more commercial seed companies operating than before, these companies tend to focus on marketing proprietary varieties of hybrid crops where biological protection allows them to protect their intellectual property. As a

result improved varieties of both hybrid and open-pollinated crops developed by the public sector are not readily available to the farming community.

Methods: ICRISAT established a partnership with the African Seed Trade Association (AFSTA) to catalyze a discussion amongst both public and private-sector seed stakeholders at national level on ways to improve the availability of improved publicly-developed varieties. Teams of three people from 22 countries representing the national seed regulatory authority, the public-breeding institute, and the national seed trade association, were invited to a series of two workshops where they were introduced to the principles of commercial seed delivery, and supported to develop a business-plan for the establishment of an independent foundation seed enterprise (FSE). The exact form of the FSE was left up to the national teams who were facilitated to organize a stakeholder meeting at national level and then to use this feedback in the development of their business plans.

In Mozambique ICRISAT has designed and provided technical support for the establishment of a financially autonomous foundation seed enterprise (FSE) to market foundation seed of publicly-developed varieties by developing a detailed business plan including financial projections for the FSE.

Milestones achieved: A seed processing facility has been established in Nampula, and seed stores constructed in Nampula, Susendenga, Chokwe, and Maputo. Contract foundation seed production has been carried out for three seasons, and foundation seed marketed both to commercial seed companies and non-governmental organizations.

Major findings: The weak implementation of seed quality standards is a disincentive for commercial seed companies and other seed stakeholders to invest in quality foundation seed that is more expensive than alternatives “seed” sources. As a result there is a weak demand for foundation seed, thus increasing the time to reach financial sustainability.

With a few exceptions none of the countries have well-established mechanisms to market foundation seed of publicly-developed varieties, and there has been no attempt to establish autonomous FSE’s with the exception of Mozambique. Financial projections developed by country teams suggest that independent FSE’s can become financially sustainable after an initial start-up period during which time external support will be needed.

Partners:

The Instituto Investigacao Agraria de Mozambique (IIAM)  
The African Seed Trade Association (AFSTA)  
The Seed Science Center – Iowa State University  
21 country teams

Publications:

Draft report business plans from Cameroon, Ethiopia, Gambia, Ghana, Nigeria, Angola, Kenya, Tanzania, Madagascar, and Mali.

***1. A.4 Web-based seed catalog to support private and public sector seed agro-enterprises (ESA)***

Project Rationale and Main Objectives: The availability of information on improved varieties and how they perform needed to help seed companies and farmers make informed decisions about which varieties to commercialize and plant is limited because national variety catalogs are poorly maintained, and where they exist contain little information. The objective of this work was to develop a web-based catalog template that could be used both as a national catalog, and to support the implementation of regional variety release agreements.

Methodology: A database was developed to contain all the distinctness-uniformity-stability (DUS) and Value for Cultivation and Use (VCU) information required by national release committees. The crops included are those that have been selected for the regional variety release system in the Southern Africa Development Community (SADC), in the Association for Strengthening Agricultural Research in Eastern and Southern Africa (ASARECA), and in the Economic Community of West African States (ECOWAS).

Milestones and Achievements: The web-based catalog and a first round of training of regional information technology staff from each of the regional economic communities completed. A second round of training and the population of the database is expected to start in early 2008. A variety comparison tool provided gratis by



Argentina has been built into the catalog so as to be able to compare varieties and avoid duplication of entries and protect the intellectual property of existing varieties.

Major Findings: There is a strong interest from national regulatory authorities to utilize the same tool to maintain national variety lists.

Partners:

ILRI

ICRISAT

Seed Science Center- Iowa State University.

***1. A.5 Enhancing formal seed systems – selected case studies (ESA)***

Funded by: Sustainable commercialization of seeds in Africa (SCOSA)

Project rationale: Carefully chosen modern varieties (MVs) can usefully increase varietal diversity and thus enhance the capacity of farmers' seed and agricultural systems, making such systems more resilient and thus enhancing food security. In promoting MVs, care must be taken to ensure that the choice of variety is adapted to the farmers' biophysical environment, as well as their local preferences and management conditions. The sustainability of any seed based initiative depends on the effectiveness of the distribution mechanism used. The ways in which a variety is promoted and distributed can influence the extent to which it is adopted by farmers. In the long run for any seed system to be viable, a successful value chain is necessary, which could be sustained through research investments in seeds and other complementary inputs.

In Niger, during early 2006, the SCOSA project supported ICRISAT-Niger and INRAN for the production of foundation seed of various modern varieties of millet, maize, sorghum and onion. The foundation seeds multiplied were distributed through different mechanisms namely: free seed samples for farm trials and demonstrations of millet and sorghum varieties across the country in different location, small seed packets of seeds distributed to vulnerable farmers through seed fairs and NGOs; and direct seed sales through INRAN outlets. A significant quantity of seeds was also provided to FAO funded community based seed projects for further multiplication.

Main objectives:

- To analyze the ways in which farmers used and/or perceived the seed in the context of local seed systems and grain marketing;
- To determine the effectiveness of the different distribution mechanisms used in transmitting seed and knowledge to farmers; farmers' perceived value of seed; potential sustainability of the various distribution mechanisms; and other factors according to the aims of the individual distribution projects
- To identify the roles of various stakeholders in the current seed value chain and highlight gaps that need to be addressed for the long term sustainability.

Milestones and achievements:

A detailed field based survey on seed users (135 farmers), producers (12) and other stakeholders such as grain traders in major grain markets (8 traders) and agri-input dealers in the seed/grain value chain for millet and sorghum was conducted in 5 major regions during May 2007 to elicit the necessary information.

Major findings (Preliminary):

- Farmers appreciate good quality seed, value appropriate new varieties and majority are willing to pay for improved seed
- Very few farmers knew names of varieties or where they came from
- Limited information channels were used to promote varieties and farmers rely on individual agents rather than organization to source improved seed
- Seed production is a viable enterprise only if there is a donor-funded project to purchase the seed they produced
- Very few markets in Niger differentiated seed and grain of sorghum and millet (Konni is exception – major market centre and favorable area for seed production). Large-scale seed marketing by traders (mostly grain) is still a project-driven activity; traders supplied seed (and sometimes grain) if they had a contract from project or donor supported projects.

- Given that there are no seed laws or regulations being implemented in Niger, the concept of seed quality in Niger is based on trust, reputation, and personal contacts.
- To conclude, grain markets in Niger require development in order to drive demand for high quality seed of specific varieties and the sustainability of any seed distribution mechanism depends on whether the farmers knew where they can access more seeds during normal and emergency times.

Partners:

ODI  
IFPRI  
ICRISAT-Niamey  
INRAN

**Output 1B: SAT agricultural research database, impact evaluation methods, participatory, pro-poor monitoring and evaluation and institutional learning and change models generated, shared and capacity developed with national and sub-regional agricultural research systems with new knowledge shared with partners.**

*1.B.1 Learning cycles and impact pathways: Determining research priorities (Global)*

Rationale: Priority-setting exercises have evolved in response to the need felt by scientists and research managers for simple and transparent procedures for making resource allocations to research projects. Research managers have come to increasingly realize that in order for research resources to be used efficiently and effectively, there should be a clear basis for setting research priorities. Complex considerations have to be weighed by the priority-setting process, and guidelines that are consistent with the broad agenda of research investment should be pursued for a problem-based, impact-driven agricultural research for development.

Major/Key findings: This study presents important dimensions of agricultural research management, featuring the considerations that go into determining priorities. It analyzes the trends that shape the agendas of agricultural research organizations. A conceptual framework for priority setting in agricultural research is presented, embodying factors influencing impacts, their linkages and minimum data requirements. An overview of priority-setting methods, ranging from simple statistical congruencies to economic models where both objective and subjective information are considered. Critical considerations in research evaluation and priority setting are addressed with focus on the difficulties encountered in practice. Experiences of international agricultural research centers are used to illustrate the commonality of priority-setting requirements and processes. The international dimension of the discussion clarifies the role of international public goods and research spillover benefits across regions, as well as the relationship between regional and global priorities. It concludes with suggestions on institutionalization based on institutional learning and targeting for an informed approach to research decision making.

Publication:

**Bantilan MCS and Keatinge JDH.** 2007. Considerations for determining research priorities: Learning cycles, feedback and impact pathways. Pages 37-64 *in* Agricultural Research Management. (Loebentein G and Thottapilly G, eds.). The Netherlands: Springer.

*1.B.2 District level database update (Asia)*

Project rationale: Update of the database is essential to address issues at the aggregate or regional level. Research resource allocations to various projects across regions have become critical due to availability of limited resources. Using district level data regions with pre determined criteria (poverty, income, infrastructure etc) could be flagged that would help in more informed resource allocation to meet the goals and objectives of the research project.

Approach and methodology: ICRISAT is maintaining a district level database for India that includes data on area and production under major crops, land use, crop wise irrigated area, source wise irrigation, farm harvest prices, fertilizer consumption, rainfall, infrastructure variables like road length, and markets, land holding size and census data relating to human and livestock population. The database spans 492 districts in India covering 16 states (now 19 states, with the formation of new states). Data were collected from the respective State Directorates of Economics and Statistics, Directorates of Agriculture, and Animal husbandry, located in each State capital.

Preliminary/major findings: Following data collection, inputting etc in 2006, in the first half of 2007 validation of data, processing and merging with existing database, making the database compatible with GIS for spatial analysis has been completed. Since 1970, several new districts have been formed for various reasons (political, linguistic, etc.). Between 1970 and 1998, 150 new districts were formed. A satisfactory method for dealing with the problem of the formation of new districts was worked out, for continuity in the dataset over time for time series analysis. At the same time a second data set with all the districts was created for conducting spatial analysis (or operationalizing GIS) using the most recent data. To complement the district level database, state and all-India database on the key variables have also been updated.

In the latter half of 2007 the database is being used for analyzing trends for mandate crops in India; feed deficit hot spots, ie, regions with surplus / deficit in feed resources in relation to livestock numbers; cropping pattern changes in rainfed agriculture etc.

Data on a number of other variables particularly infrastructure variables like roads, markets, institutions, veterinary services, healthcare education etc still need to be included in the data set to make it more holistic and useful for social science researchers.

Partners:

CRIDA : B Venkateswarlu  
ICRISAT : P Parthasarathy Rao  
ILRI : Michael Blummel  
IWMI : Madar Samad

### ***1.B.3 Enhancing impact and impact pathway analysis (Global)***

#### *1.B.3.1 A synthesis of lessons learned on the impact pathways in Asia*

The impact assessment research agenda for the next five years 2007-2011 has been developed. This was done in coordination with scientists, Global Theme Leaders, and Directors across themes and regions (both core and special projects). This was submitted and approved for implementation by the Director General.

For 2007, the implementation and completion of impact pathway analysis includes:

- *Synthesis of Chickpea research impact studies conducted in India, Myanmar and Bangladesh (Asia)*

Andhra Pradesh, India: Between 1972-74 and 1998-2000, chickpea area in Andhra Pradesh increased by 130%. In the same period, the productivity of chickpea doubled from 337 to 677 kg per hectare. The production of chickpea in Andhra Pradesh increased by 366% during this two and half decade period. A study was taken up in 2002 by ICRISAT in collaboration with ANGRAU to assess adoption of improved chickpea cultivars and their impact on increasing yields and incomes of farmers. While the survey instruments were developed by ICRISAT, the survey was conducted by ANGRAU. The adoption surveys were done with 500 farmers belonging to 20 villages from 10 mandals in Guntur, Prakasam, Kurnool, Anantapur and Cuddapah districts. The impact was assessed from the data collected from a sub-sample of 125 farmers. ICRISAT cultivars, ICCV-2 and ICCV-37 occupied 40% area in Guntur district, 33 % area in Prakasam district and 27% area in Cuddapah district. But their penetration was negligible in case of Kurnool and Anantapur districts due to non-availability of the seeds of ICRISAT cultivars. Annegiri (an improved variety released two decades ago) continued to occupy the major areas in these districts. Most of the spread of ICRISAT varieties occurred by farmer to farmer contact rather than by the recommendations given by the extension department. Farmers preferred the traits of high yield, wilt resistance and pest resistance to be the desired traits in the new cultivars. Chickpea was more profitable than the competing crops, black gram, maize, sunflower and soybean in all the study districts. ICCV-37 performed better than Annegiri, especially in Prakasam and Cuddapah districts. The returns from ICCV-37 were higher by Rs.1985 per hectare when compared to those from Annegiri. But ICCV-2 fared worse than Annegiri in terms of yields and returns. Farmers perceived higher returns from better agronomic practices than from the improved cultivars. They stressed the need for government initiatives for producing seeds of improved cultivars and for making them available to the farmers especially in Kurnool and Anantapur districts.

Maharashtra, India: Between 1970 and 1996, the area under chickpea grew at a compound growth rate of 2.78% while the productivity of chickpea increased at a growth rate of 3.22% per year. As a result, chickpea production increased at a growth rate of 6.11% per year. The adoption and impact surveys were carried out by ICRISAT in 2001 and 2002 in three districts of Vidarbha and two districts of Marathwada. Out of the five districts covered in this study, Akola, Buldhana and Amravati (all belonging to Vidarbha) recorded even faster rates of growth in production than the state average, while Aurangabad and Nanded (both belonging to Marathwada) registered lower growth rates than the state average. The study covered 200 farmers from 20 villages in ten blocks of these five districts. ICRISAT varieties which included ICCV-2, ICCV-3, ICCV-37, ICCV-88202, ICCV4958, JAKI-9218 and Vishal together had a share of about 37% in the total area under chickpea on the sample farms. The non-ICRISAT improved varieties like Phule G-5, Phule G-12, Vijay, Dollar and Kabuli bold had a combined share of 42% in total area under chickpea on sample farms. ICRISAT varieties occupy major areas in Akola and Buldhana districts while non-ICRISAT improved varieties are doing better in the other three districts. The local varieties still occupied 11%. The ICRISAT varieties, ICCV-37 and Vishal spread fast during the late 1990's but are giving way to other improved varieties like Vijay and Dollar in 2000 and 2001 seasons. ICRISAT varieties gave higher returns than the local varieties to a tune of Rs.2756 per hectare. But they were just at par with the other improved varieties in terms of yields and profits. There seem to be better arrangements for seed systems for the varieties developed by Punjabrao Krishi Vidyapeeth, Akola and Marathwada Agricultural University, Parbhani than for the ICRISAT varieties. More than 50% of the farmers retained their own seed for the next season while one-third of the farmers purchased seeds from the seed shops and the remaining 12% obtained the seeds from other farmers. Higher grain yield, short duration, drought and disease resistance are the major traits preferred by farmers in the new cultivars. Lack of awareness, lack of irrigation and non-availability of improved seeds on time are the major constraints faced by chickpea growers in adopting new cultivars.

Myanmar: The study was carried out to assess the adoption and impact of improved chickpea varieties in Myanmar. Three major chickpea growing divisions, Magwe, Mandalay and Sagaing, were selected and data was collected using a pre-tested questionnaire on a random sample of over 240 households. Each household on an average operated 3.08 ha of dry land and 2.51 ha of irrigated land. Dairy was the main source of livestock activity with each household owning about 3 cows. Goat rearing was taken up in Mandalay and poultry was being practised on a homestead scale. Each household comprised an average of 2.0 males and 1.6 females working on their own farms. The average share of agriculture income accounted for 85% of the total income followed by livestock income. On an average, about 18% farmers owned tractors, 16% owned threshers and 25% owned pump sets.

Chickpea cultivation was not new to the farmers of the region, as two-third of them had been cultivating it for well over five years. However, there has been a renewed interest in chickpea cultivation in recent years with about 25% of the sample farmers starting cultivation during the last two years. In addition to this, the farmers have been increasing the existing area under the crop quite substantially mainly due to its good market acceptability and economy in labour requirement. The area under chickpea has been increasing replacing crops like wheat and sunflower, and to a lesser extent at the cost of post-rainy season rice and sorghum. ICCV 2 was the most preferred cultivar followed by ICCV 88202 and ICCV 92949. The highest adoption was observed for ICCV 2 and ICCV 88202. These varieties were replacing local cultivars and were also adopted by new cultivators of chickpea. The extension agencies and farmers played a key role in promoting improved chickpea cultivars. About 95% of the farmers did not experience any difficulty in procuring seed of improved varieties. The farmers generally obtained seed from fellow farmers as gifts (52% cases) or through purchase (48% cases). Majority of farmers indicated Helicoverpa pod borer as a major constraint to chickpea production followed by diseases. About one fifth of the farmers did not experience any major production problem in chickpea cultivation.

The cultivars ICCV 2, ICCV 3 and ICCV 88202 had relatively higher production efficiency as compared to local cultivars including the old cultivar Karachi. Cultivation of all chickpea cultivars was found to be very profitable. The yield levels of ICCV varieties were higher than Karachi and local cultivars. The output decomposition analysis revealed that ICCV 2 and ICCV 88202 gave 103% higher yield than the local varieties grown by the sample farmers. Of this difference, the total contribution of technology was about 73% of which neutral technology alone contributed around 63%. This shows that the technology embodied in these cultivars are scale neutral and hence the benefits could be derived by all categories of farmers. The Kabuli varieties ICCV 2 and ICCV 3 gave the highest net returns per unit of cost as these varieties realised a higher unit price in the market. This is corroborated by the farmers' opinion that chickpea had good market acceptability. The main crop replaced by chickpea was wheat in about 50% of the cases.

Bangladesh: The study-conducted to assess the impact of chickpea research in Bangladesh was based on a sample of 216 households drawn from Chapai Nawabgonj, Naogoan, Nawabgonj and Rajshahi districts of Bangladesh. Agriculture was the major source of income followed by dairy and wage income in these districts. Chickpea, rice, boro, wheat and Aus were the major crops grown by the sample farmers. Among the chickpea cultivars Bari-1 was the most popular followed by Bari-5. Local cultivars were also very popular. The Bari series of cultivars yielded around 275 kg per ha and in comparison to this the local varieties yielded only 150 to 200 kg per ha. Perhaps the farmers grew local cultivars to meet their family requirement of chickpea rather than for the market. Insect and diseases were the major production problems facing Bari-5 and Bari-4 cultivars. Bari-1 was susceptible to droughts as perceived by the farmers. However in recent years most of the production problems had diminished barring droughts, which had tended to increase. Farmers had between 8 to 10 years experience in growing chickpea. Bari-1 was adopted since early 1990's whereas Bari-5 is of a more recent vintage gaining popularity since the mid-nineties. A large area was under the Bari cultivars, which is a testimony of the technical superiority of these cultivars. Analysis of output differentials between Bari-1 and Bari-5 revealed that technology contributed around 78 percent to the yield differentials in the former over the latter. Further the technology manifested itself in terms of greater technical efficiency in Bari-1. Bari-1 was perceived as being similar to Bari-7. Bari-2, Bari-3 and Bari-4 were different from Bari-1 on the basis of yield characteristics perceived by the farmers. The chickpea varieties introduced into Bangladesh were the most popular ones and had contributed to increasing the yield levels quite significantly. The new varieties were also technically more efficient than the existing cultivars grown in the country, which would help in conserving scarce resources used in the production of chickpea.

- *Baseline studies on groundnut, chickpea and pigeonpea is scheduled for implementation starting the rabi season of 2007 (for chickpea) under the Tropical Legumes 2 project with support from the Gates Foundation.(Global)*
- *Empowerment through social capital build-up: gender dimensions in technology uptake (Asia)*

This study explores how and to what extent women and men have benefited from social capital build-up (the ability of men and women farmers to develop and use various kinds of social networks and the resources that thereby become available) in technology uptake, and the role of women in this process. Using a series of three case studies on ICRISAT's Groundnut Production Technology, the process of technology uptake leading to empowerment is systematically documented through three stages of the adoption pathway. – a) in the early stage of adoption where lack of collective action is learned to be a constraining factor in technology uptake; b) a subsequent stage after the learning phase when the constraint is lifted through social capital build-up and it is seen as a mediating factor effectively facilitating technology adoption; and c) an ultimate stage of individual and community empowerment whereby even marginalized groups including women and tribals gained better access to resources, information, knowledge and some opportunities for political participation. An analysis of the process stimulating gender-equitable change and empowerment is undertaken using documentations of these studies undertaken from 1992 to 2003. The process stimulating gender-equitable change and empowerment is examined through a sequential analysis using two in-depth case studies in three villages in Maharashtra, India, and complemented by a broader quantitative study of the uptake process covering villages in surrounding districts.

The learning from this study illustrates that social capital is important for both adoption and impact to occur. Qualitative information complemented by quantitative measures provide a holistic understanding of the long term effects and benefits. The findings illustrated that build-up of social capital strengthens the access to resources like credit, information and knowledge about new technology options and practices. Furthermore, it expands choices available to each household member eg. selecting and adopting seed technology of their choice, and alternative investment options; and influences the distribution of benefits from the technology because of the ways in which social networks and social relationships facilitated technology dissemination. Mobilizing social capital through participation of men and women in groups/networks that crossed caste, class and gender barriers mediated the successful adoption and diffusion of technology.

- *Feasibility study an ex ante evaluation for sweet sorghum research: First phase and target completion in 2008 (Asia)*

Sweet sorghum as a feedstock for bio-ethanol production holds promise in the context of rising crude petroleum prices, high yielding varieties and hybrids on the research stations and new innovations in processing technology. M/s Rusni Distilleries Ltd has set up a processing plant with a capacity to produce 40,000 liters of



ethanol per day in Medak district of Andhra Pradesh. It has supplied the key inputs on credit to 791 farmers and provided extension services with the help of ICRISAT and non-governmental organizations during the rainy season of 2007.

Project objective: An ex-ante evaluation of sweet sorghum in Medak district of Andhra Pradesh

Approach and methodology: After preparing a feasibility report on the viability of sweet sorghum, a detailed survey was conducted with 200 sample farmers in Doulothabad, Jogipet, Sadashivpet and Jharasangam areas of Medak district. While the data entry and analysis of the survey data is in progress.

Milestones:

- Preparation of the feasibility report
- Data collection and data entry
- Data analysis
- Report submission

Preliminary findings/Major findings: The NTJ-2 variety performed reasonably well under rainfed conditions. But, since most of the sowings clustered around a few dates after the onset of monsoon, the green stalk of sweet sorghum was ready for harvest at the same time. The new factory experienced technical, operational, labor and financial difficulties due to which it could not operate at more than 50% of its capacity. The procurement of stalk was delayed, very much degrading the quality of stalk and the ethanol output from it. Both the processor as well as the farmers incurred substantial losses, which could have been avoided if there was anticipatory planning and preparations to handle the situation. Many of the growers are hostile and it is doubtful that they will plant sweet sorghum again in the next season.

The stalk yield of sweet sorghum, which was only about 8 tons per hectare during 2006-07 when it was taken up on a trial basis, increased to about 15 tons per hectare during 2007-08 due to input supply and technical guidance. If the hybrid varieties, which are performing well on the research stations, are taken to the farmers along with extension support and input supply, the stalk yields during the rainy season could be increased to 25 tons per hectare. If that happens, sweet sorghum can compete well with crops like maize, green gram and grain sorghum in the districts surrounding the factory area. The processor should lift the stalks in time to ensure good yields for farmers and good ethanol recovery for himself.

A number of decentralized procurement models could be tried to ensure timely procurement of sweet sorghum stalk by involving farmers, farmers' co-operatives, local village agents, self-employed entrepreneurs and processor in a variety of functional relationships and buy-back contracts. At first, the potential of technology has to be demonstrated in the field and the confidence of farmers has to be won back through timely procurement in the next season even if it means planning for a lower scale of operation. Even in the decentralized models, the viability of the crushing and primary processing units (into syrup and jaggery) has to be established at a pilot scale. Then, the alternate models of establishing viable and de-centralized units could be tried to test them for feasibility and distribution of benefits, particularly to the poor farmers.

Partners:

ICRISAT  
Rusni Distilleries Ltd  
AAI

Publication:

**Rao KPC.** 2007. Socio-economic models for integrating the poor into large-scale sweet sorghum feedstock supply chains in dryland India. Paper presented at the global consultation on pro-poor sweet sorghum development for bio-ethanol production and introduction to tropical sugar beet, jointly organized by IFAD-FAO-ICRISAT at IFAD, Rome 8 - 9 November 2007.

- *A synthesis of lessons learned on the impact pathway for pigeonpea, groundnut and chickpeas in ESA and NRM in WCA (SSA)*

During 2007, an intensive technology promotion was undertaken for pigeonpea and groundnut in Kenya. The promotion of chickpea varieties was undertaken in Ethiopia in collaboration with the EIAR and IPMS project (hosted by ILRI). In order to understand the key constraints in the impact pathway, ICRISAT synthesized the

key lessons from pigeonpea impacts in Kenya and Tanzania. A value chain assessment was also completed for chickpea in Ethiopia. In addition, ICRISAT along with NAADS and NARO carried out a large-scale groundnut adoption survey covering seven districts and 945 households. The key findings from this study are summarized in a poster to the Governing Board.

The main results from the pigeonpea studies in Kenya and Tanzania show that access to improved seed remains to be the major limiting factor for farmer adoption. In northern Tanzania (based on data from Babati district), the adoption of the technology has increased from 25% in 2003 to 34% in 2004 and is expected to have reached 60% of pigeonpea farmers during 2007. This technology needs to be scaled up to other parts of the country. In collaboration with local partners, the TL-II project will expand adoption of fusarium resistant varieties to other target areas. In Eastern Kenya, the adoption levels are also quite high. About 55% of the pigeonpea farmers surveyed in two districts (Makueni and Mbeere) grow improved ICRISAT varieties. Seed availability has been enhanced through successive projects supported by USAID and USDA. During the last 3 years, the Lucrative Legumes project (LLP) supported by USDA has channeled more than 12 tons of improved variety seed, reaching more than 14,000 farmers. The LLP project also distributed over 60 tons of groundnut seed in Western Kenya, reaching more than 11,000 farmers.

In Ethiopia, several Desi and Kabuli type chickpeas have been released. With the support of the IPMS project, ICRISAT and EIAR conducted on-farm trials and demonstration plots to promote new varieties. Seed production was facilitated through the Ethiopian Seed Enterprise and the Farmer Cooperatives who contract trained seed producers. Improved market linkages, increased availability of seed and better prices have stimulated high variety uptake for Kabulis in Ethiopia. About 37 t of Kabuli seed was distributed during 2006, reaching more about 1750 farmers. During 2007, this increased to 110 tons reaching about 5200 farmers. Much of the effort so far has concentrated in three districts (Ada'a, Akaki and Gimbichu). Other areas are now targeted for scaling up the promising varieties under the TL-II BMGF project. Improved market linkages, availability of improved seed, awareness and credit facilities for resource-poor farmers are critical factors in the adoption pathway.

For groundnuts in Uganda, the adoption of Rosette resistant varieties has been very significant. In the seven districts surveyed, about 54% of the sample farmers have adopted new varieties. This indicates that in the seven districts alone more than 200,000 farmers are growing new varieties. The income gains for small farmers are quite significant. The active involvement of the national extension service (NAADS) in seed production and extension has led to extensive uptake. Poor market access and limited knowledge about aflatoxin management are major factors that limit smallholder benefits from the improved technologies.

*Uptake of soil and water conservation (S&WC) technologies in a degraded area of Mali: the Office de la Haute Vallée du Niger (OHVN) – Lessons and experiences*

This report analyses the survey results on uptake of soil and water conservation (S&WC) technologies in a degraded area of Mali: the Office de la Haute Vallée du Niger (OHVN). Twenty-six villages were purposely selected and a total of 531 rural households were randomly selected and interviewed. Data were collected using focus group interviews at village level and structured questionnaires at household level. The major objectives of the survey were to characterize, identify and evaluate potential environmental, socio-economic, institutional and technological constraints to uptake of S&WC technologies, identify the level and determinants of uptake of S&WC technologies, and assess factors explaining household perception of welfare changes.

Survey results show that a range of factors may explain uptake of soil and water conservation methods. First the process that was used to disseminate technologies. The natural resource management program of the OHVN has been largely involved in disseminating soil and water conservation methods in the South of the OHVN zone. This region was suitable for cotton production which was the major emphasis of the NRM program of OHVN. Technologies that were widely used are also those that were disseminated. These include stone bunds, stone lines, living hedges, vegetative bands and branch barriers. Second, the levels of endowments in livelihood assets and transforming structures such as markets and institutions are also drivers to uptake of technologies. In effect, village uptake was relatively high where there was better road infrastructure, better soils for cotton production, markets, access to fertilizers through credit provided by OHVN, and institutions such as health, education and farmers' organizations.

At household level, results show that 40% of the households have adopted at least one S&WC conservation technology. Stone lines and stone bunds are the most widely adopted technologies. Vegetative bands, wood

barriers and living fences are adopted by more than 5% of households. Adoption is concentrated in the southern part of the OHVN zone where the OHVN program has largely disseminated technologies. Users of S&WC technologies have more livelihood assets than non-users. On average, users have more work force, more educated members, own more land, livestock, agricultural equipment, cash income and consumable assets than non-users. Except for half-moon, most farmers reported that these technologies generate high productivity gains estimated between 20 to 60%.

At plot level, the same trend is observed as at household level. Results indicate that households have applied at least one soil and water conservation technology in 20% of their cultivated plots. Stone lines and stone bunds are used on 10% and 5% of the plots respectively. Users of the soil and water technologies apply more fertilizers per ha than non-users; 53 kg/ha against 30 kg/ha. Fertilizer application differs significantly by crop. Fertilizer use intensities are high in "high value" crops such cotton and maize and farmers use little fertilizers in other crops. Farmers own on average 3 plots and grow a range of crops including sorghum, millet, cowpea, groundnut, maize, rice and cotton. They plant a single crop in half of their plots. Plots largely differ based on their characteristics but there is no significant differences between users and non-users except in their perception of fertility and production levels.

Households' perception of changes or productivity levels do not necessarily tally with estimated yields of major crops. Except for sorghum and cotton, there are no significant differences in yields between users and non-users of S&WC technologies. This raises questions on whether there are productivity gains derived from using these technologies. This question is difficult to address because of lack of baseline data to assess the situation before and after the project. It may well happen that the productivity in some areas was very low and that with the use of soil and water conservation methods it has significantly increased. This may be the case for the South of the OHVN zone where water erosion is more important than in other OHVN regions. In addition, due to lack of monitoring and evaluation of technologies, it is difficult to assess the trends in yields in the OHVN region.

Overall, 75% of households users of S&WC technologies reported to have accumulated more assets and are more food secure from 1995 to 2002. In addition, more than 80% of the households claimed large improvement in health, education and access to potable water. However, it remains difficult to attribute changes in overall well-being to the impact of soil and water conservation technologies alone. Many other interventions may be partly responsible for these changes. In effect, likewise in the case of the assessment of productivity gains, a baseline is necessary to better assess the impact of soil and water conservation measures.

Households likely to use soil and water conservation technologies are those involved in cash crops (such as cotton); better equipped, generate more liquidity from crop, livestock or off-farm income, better perception of plot fertility, younger, and relatively better educated. In addition, households with large plot area, private plots, with plots located more in slopy areas are likely to use soil and water conservation technologies. Policies likely to improve farmers' access to credit to purchase agricultural equipment, improve education, provide alternative livelihood options to farmers are likely to improve uptake of soil and water conservation technologies.

*Smallholder adoption and adaptation of natural resource management interventions in the semi-arid rainfed systems: Market, policy and institutional lessons and experiences*

**Introduction:** Despite the increasing efforts made and the growing policy interest, spontaneous and widespread adoption and adaptation of technologies and innovations for sustainable management of land and water resources by smallholder farmers outside of intensively supported project locations has generally been limited. Smallholder farmers and resource users continue to face difficulties in adoption and adaptation of soil and water conservation technologies. The diagnosis of these changes and lessons from different examples show that several factors have indeed contributed to the continuing challenges facing smallholder farmers in adoption and adaptation of sustainable land and water management interventions – ranging from the poor performance of the technologies themselves to policy and institutional deficiencies at different levels.

An area where more evidence has emerged in recent years is on the role of using landscape-wide interventions to internalize the externalities and policy failures that undermine incentives for private investment. Watersheds are ecologically and socially complex geographical units characterized by interdependence between overlapping resources as well as resource users (communities). Watershed resources (soil, water, trees, biodiversity, etc) are utilized by diverse groups of people holding unequal use rights and entitlements. Social differentiation and unequal access often create conflicts between those inhabiting and utilizing different components of the watershed resource (eg, upper, middle and lower reaches). Given this complex social and biophysical

interdependence, collective action among diverse stakeholders is the key for effective management of watersheds. This throws up a wide range of issues, such as social organisation and property rights that need careful scrutiny in order to sustain and improve the effectiveness of the program.

Several case studies have shown that community participation in watershed activities, especially in India, has been generally poor. Various factors spanning the biophysical conditions and institutional and policy environments have contributed to this outcome. Distribution of programme benefits is one of the most vital factors in determining watershed collective action (CA). Equitable distribution of benefits, especially to the poor and marginal farmers, increases the incentive to cooperate. Participation in linked income-generating options such as collective marketing could also further improve incentives for watershed collective action. The absence of clearly defined property rights is at the root of the failure of participatory watershed development in majority of the cases. Property rights are clearly biased against the landless and the landed poor as far as the distribution of benefits is concerned. While collective action can lead to establishment or changes in the existing system of property rights, few communities have actually adopted new property rights systems that promote equitable and sustainable management of watershed resources.

Objectives of the study: Taking a broader view, this study reviews African and Asian experiences in promoting soil and water conservation and sustainable land management technologies. It synthesizes lessons from various case studies and offers new insights on approaches and strategies that accelerate widespread adoption and adaptation of such interventions. The allied study also investigates the institutional and policy issues that limit effective participation of people in community watershed programs and identifies key determinants for the degree of CA and its effectiveness in achieving economic and environmental outcomes. Based on review of experiences and the empirical evidence in implementing IWM programs especially in India, the study offers some new insights on future strategies for strengthening institutions for collective action to enhance the poverty and environmental impacts of watershed programs in India.

Methods: We use an extensive literature review to synthesize lessons across Africa and Asia on key policy relevant factors that determine private and community investments in sustainable land management. One journal article and two book chapters are produced from this effort. This is complemented by empirical data from a survey of 87 watershed communities in semi-arid Indian villages to identify a set of indicators of Collective Action and its performance in attaining desired outcomes. Factor analysis is used to develop aggregate indices of CA and its effectiveness. Regression methods are then employed to test the effects of certain policy relevant variables and to determine the potential effects of CA in achieving desired poverty reduction and resource improvement outcomes. We find a positive and highly significant effect of CA on natural resource investments, but a weaker positive evidence of its effects on household assets and poverty reduction outcomes. This is attributable to longer gestation periods for realizing indirect effects from collective natural resource investments and the lack of institutional mechanisms to ensure equitable distribution of such gains across the community, including the landless and marginal farmers.

Major outputs:

- Journal articles and papers on lessons and experiences from adoption and adaptation of NRM interventions in Asia and Africa
- The functional evolution of local institutions and the major determinants of farmer participation in watershed management identified and targeted for policy
- Policy brief on current policies and future policy needs for viable CA in watershed management and the role of property rights, existing policies and institutional set ups and their influences on CA
- Strategies for enhancing the participation of farmers and women groups in watershed management developed and promoted
- Institutional mechanisms and organizational innovations for integrated watershed management identified and comparative lessons drawn

Major findings: Review of the wide literature shows that resource poor farmers, especially in marginal and rainfed regions, continue to face complex challenges in adopting and adapting alternative management practices and innovations for mitigating this problem. In an effort to address this challenge, the approach to soil and water conservation itself has evolved over several phases; latest perspectives encouraging the need to ensure farmer participation and consideration of market, policy and institutional factors that shape farmers' incentives. The need for farmer participation and innovation is justified by the fact that most soil and water management problems tend to be site and even farm specific. This calls for the need to provide farmers with a set of options

to fit specific niches depending on specific constraints rather than a wholesome “one-size-fits-all” type approach that promotes a single technological package in all areas.

The review also indicates that adoption and adaptation of land and water management innovations is constrained by failure to link conservation with livelihoods, extreme poverty and imperfect factor markets, inadequate property rights systems, and weak organizational and institutional arrangements at different levels. The best way to ensure adoption of innovations for sustainable land and water management is to develop them iteratively, in collaboration with the target group. This can be done through linking formal research with indigenous innovation processes of local resource users and communities. Effective soil and water conservation interventions are characterized by a process of joint innovation that ensures farmer experimentation and adaptation of new technologies and management practices and careful consideration of market, policy and institutional factors that condition and shape farmer conservation decisions.

Linking farmers to better markets for their produce and inputs like fertilizer and credit generally makes a positive contribution in raising the returns to land and labor in agriculture. When complimented with proper policies and institutional mechanisms to induce the process of farmer innovation and adoption of conservation practices, market access can be a useful driving force towards sustainable intensification of smallholder agriculture in both rainfed and irrigated areas. Given that investment poverty and lack of farmer capacity can be major limiting factors for certain sustainability-enhancing investments, access to investment credit at farmer affordable rates and availability of pro-poor options for beneficial conservation (ie, offer short-term livelihood benefits) will be an important step in solving some of the long-standing constraints.

In addition, experience has shown that projects should act as ‘toolboxes’, giving essential support to resource users to devise complementary solutions based on available options, rather than imposing exogenous practices and technologies. If investments in the resource provide a worthwhile return and when enabling policy and institutional arrangements empower individual resource users and communities, smallholder farmers often try to protect their land and water resources from degradation. The major challenges for future land and water management will be in addressing the externalities and institutional failures that prevent joint investments for management of agricultural landscapes and watersheds. This will require new kinds of institutional mechanisms for empowering communities through local collective action that would ensure broad participation and equitable distributions of the gains from joint conservation investments.

Finally, some of the key lessons for the future include: (a) future land and water conservation projects should be flexible enough to respond to land users’ innovations and inputs; (b) land and water conservation interventions should favor approaches that provide a number of different technologies and management practices, which individual resource users can choose, test, adapt and adopt or discard as they see fit; (c) resource-poor farmers are unlikely to adopt interventions that do not provide short-term economic gains, especially when credit markets and property rights are imperfect to permit investments with long payback periods; (d) adoption requires a conducive institutional and policy environment and good linkages with product and factor markets to enhance the returns to beneficial conservation investments; and (e) integrated and landscape-wide interventions require community participation and collective action to coordinate and regulate resource use and investment decisions.

Using empirical data from India the results show that the level of collective action was affected negatively by the size of the groups (number of households and area of the village) but high levels of rainfall seem to reduce the incentives for collective action. The degree of collective action also seems to increase with equitable distribution of benefits and preference given for employment of the rural poor and female workers. However, the results clearly show that in most watershed communities the level of collective action is very limited, indicating that only few communities have achieved higher active participation of resource users in watershed programs.

At the same time, we also found only few (10-15%) watersheds that were able to harness the potential of collective action to achieve desired economic and environmental objectives. There is a strong correlation between higher levels of collective action and higher performance of communities in facilitating resource improving investments, especially water-harvesting structures and good management of these resources. The effectiveness of watershed groups in terms of their performance on this index depended on other variables like rainfall, conflict management, social diversity (share of marginal and landless groups) and the quality of the road linking the village. On the other hand, the correlation between higher collective action and changes in the index of poverty parameters was positive but weakly significant. The analyses also showed that changes in



watershed natural resource stocks did not have a significant effect on changes in household welfare, indicating that the indirect effects of collective action are still limited. This offers evidence that the links between collective action and poverty are not always straightforward as distribution of rights and other factors will condition how effectively the poor will be able to benefit from improved natural resource conditions within the watershed.

Overall the results indicate that collective action has made a significant contribution in terms of improving the investment and management of critical jointly held resource assets (eg, wells, ponds, check-dams, community forests, grazing land, etc), but there is a weaker evidence on its effects on improving the asset endowments of the resource poor and reducing poverty levels within the semi-arid watershed villages included in this study. In order to improve active participation of the resource users and the poverty impacts of watershed programs, there is a need to promote pro-poor interventions and institutional arrangements that enhance equitable sharing of both costs and benefits.

The absence of clearly defined property rights is at the root of the failure of participatory watershed development in majority of the cases. Property rights are clearly biased against the landless and the landed poor as far as the distribution of benefits is concerned. While collective action can lead to establishment or changes in the existing system of property rights, few communities have actually adopted new property rights systems that promote equitable and sustainable management of watershed resources.

While technological and institutional options for watershed development are well understood, scaling up of such options in an efficient and effective manner is proving to be the main bottleneck Watershed management therefore calls for policy and institutional interventions that enhance collective action among the diverse resource users.

Partners:

University of Nairobi  
Center for Economic and Social Studies (CESS)  
BAIF Research and Development Foundation  
Humboldt University

Publications:

**Reddy VR, Shiferaw B, Bantilan C, Wani S and Sreedevi TK.** 2007. Collective action for integrated watershed management in semi-arid India: strategic policy and institutional options. Policy brief no. 11. Patancheru 502 324, Andhra Pradesh, India: International Crops research Institute for the Semi-Arid Tropics.

**Shiferaw B, Tewodros A, Kebede and Reddy VR.** 2007. Community watershed management in semi-arid India: The state of collective action and its effects on natural resources and rural livelihoods. Paper presented at the CAPRI Policy Conference, Feb 28 – March 2, 2007. Entebbe, Uganda.

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**Twomlow S, Shiferaw B, Cooper P and Keatinge JDH.** Forthcoming. Integrating genetics and natural resource management for technology targeting and greater impact of agricultural research in the semi-arid tropics. Journal of Experimental Agriculture.

**Shiferaw B, Okello J and Reddy VR.** Forthcoming. Adoption and adaptation of natural resource management innovations in smallholder agriculture: Reflections on key lessons and best practices. Environment, Development and Sustainability.

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**Shiferaw B and Okello J.** Forthcoming. Stimulating smallholder investments in sustainable land management: Overcoming market, policy and institutional challenges *in* Determinants of Investments in Sustainable Agriculture in East Africa, Resources for the Future (Bluffstone, R. and Kohlin, G. eds.),. In Press.

#### ***1.B.4 Cost of cultivation and impact assessment for sorghum and pearl millet (Asia)***

Project rationale: The CFC-ICRISAT-FAO project entitled 'Enhanced utilization of sorghum and pearl millet grains in poultry feed industry to improve livelihoods of small scale farmers in Asia' is implemented by ICRISAT with the participation of local partners in China, Thailand and India. The project is funded by CFC and monitored by FAO. In India the project is enforced in two clusters of Andhra Pradesh and three clusters of Maharashtra. The ultimate objective of the project is to increase the farmers' income by 10-15 percent in three years.

Project output: Assessment of effectiveness of project activities and project findings and dissemination of these findings outside of the target areas. Conduct final surveys for assessing impact.

Approach and methodology: Under this project, in Andhra Pradesh and Maharashtra clusters, improved varieties of sorghum and pearl millet along with improved package of practices were promoted. Also the produce was marketed in an innovative way this year, which has yielded better prices for the farmers. A questionnaire survey on cost of cultivation was carried out to quantify the increased returns due to the improved technology and per unit cost of production. These were compared with the baseline survey that had been carried out prior to the start of the project.

Preliminary/major findings: The findings of the survey are presented cluster-wise below.

##### *Andhra Pradesh:*

Palvai : The gross income of the pearl millet farmers has increased to Rs 18,348 per ha during 2006-07. The net returns accrued by the farmers after excluding all the expenses is about Rs 7180 per ha, which is higher compared to earlier income of Rs 2943 per ha in 2004-05. The benefit cost (BC) ratio of 2006-07 has increased to 1.6 over the base line results of 1.3.

Udityal: The gross income realized by the farmers of Udityal cluster has increased to Rs 18,268 per ha from Rs 7,808 per ha during the baseline year. The grain yield is increased by 96 percent and the prices are increased by 31 percent. The bulk marketing also reduced the marketing cost by Rs 10-12 per bag. Hence, the net returns realized by farmers after excluding all the expenses is about Rs 6850 per ha, which is higher compared to baseline year income of Rs 483 per ha in 2004-05. The BC ratio has increased to 1.59 in 2006-07 with the project impact as against 1.06 in the baseline year.

##### *Maharashtra:*

Kok : The gross income of the farmers in 2006-07 rose to Rs. 22,240 per ha from Rs.12,638 per ha in the baseline year 2004-05. The total return realized from grains is Rs 15,505 in 2006-07 as against Rs.9033 per ha in the baseline year. Excluding all the expenses the net return realized by an average farmer is Rs 13,658 per ha in 2006-07 against Rs. 7870 per ha in the base year. The benefit cost ratio is 1.70 as against 1.19 showing a marked improvement.

Anjanpur : The total return realization from grains is Rs 15,240 in 2006-07 as against Rs. 10,823 per ha in the baseline year. The average income realized from selling the fodder is Rs 5905 per ha as against Rs. 5735 per ha, which takes the gross income to Rs. 21,145 per ha in 2006-07 as against Rs.16,558 per ha in the baseline year. Excluding all the expenses the net return realized by the farmer from one hectare is Rs 14,263. The benefit cost ratio for the cluster is 2.03 as against 1.84 in the baseline year.

The survey showed that the cost of cultivation of sorghum and pearl millet has increased in current year over the baseline year, 2004-05. But this is justified by increase in productivity and production of sorghum & pearl millet. Along with the increased production, quality of grains and fodder is also good over the previous year that is fetching higher prices. The marketing costs of grains have been reduced by 50-60% compared to the previous year by implementing bulk-marketing model.

Impact assessment: The CFC-ICRISAT-FAO project entitled ‘Enhanced utilization of sorghum and pearl millet grains in poultry feed industry to improve livelihoods of small-scale farmers in Asia’ will be completing its final year in operation and hence the impact of the project needs to be assessed. While it is not feasible to expect to measure the real welfare impact at the district and village level at the end of a three year project, we can expect to see a quantifiable impact at the household level in certain key parameters that can be sustained beyond the lifetime of the project. The impact assessment will be carried out in December 2007 after the rainy season crop is harvested. In the meantime, the methodology for impact assessment and sampling design have been finalized as indicated below.

Approach and methodology: The benchmark for comparison of the key parameters is the baseline data available for the project clusters under the project prior to the start of the project. Additionally, farmers from control villages (not participating in the project) will be surveyed for a ‘With and Without comparison’ that is, with project intervention and without any intervention.

A three-tier approach consisting of the following aspects towards conducting the impact assessment study will be followed:

- Macro level indicators, which would include a survey of the key interventions, such as infrastructure created, credit linkages, input and output linkages created, and quantify the number of beneficiaries under the project.
- Household survey to observe impact on income and social status through technological, economic and social dimensions and evaluating input, market, and credit access.
- Stakeholders’ opinion analysis which would include the views and opinions of some of the key stakeholders such as bankers, poultry farmers and feed manufacturers, PEA, project partners, Farmers’ Associations, Village Leaders and Consultants would be presented to understand what each stakeholder group thinks about the success and impact of the project. This would also incorporate suggestions on how to make the project sustainable in the long run.

In summary, the impact assessment study would provide a comparison of the benefits to the beneficiaries under the project compared to their status at the start of the project. The key indicators are:

- Area under Target crops
- Yield of Target crops
- Quality of grains
- Inputs cost per unit of produce
- Prices obtained and net returns
- Marketing cost
- Market access and bargaining power
- Credit linkages
- Input linkages
- Storage quantity
- Formation of Farmer’s Association and capacity building of farmers.

The methodology and sampling frame for impact assessment is being shared with partners in China, Thailand and India.

Partners:

Andhra Pradesh : FFA, SVVU, Janaki Feeds Private Limited  
Maharashtra : MAU, KVK- Beed, VHL  
Karnataka : UAS- Dharwad, NGO  
China : SRI-LAAS  
Thailand : FCRI/FCRC

Publications:

**CFC/FAO/ICRISAT.** 2007. Assessment of cost and return economics of the improved cultivars and better management practices on the farmers. Region 1, India. Project Executive Agency (PEA), CFC / FAO/ ICRISAT project ICRISAT, Patancheru

**Parthasarathy Rao P, Gurava Reddy K, Reddy BVS, and Ramchandriah D.** 2007. Farmers' perceptions on performance and utilization of improved sorghum cultivars. *Manage Extension and Research Review*. Vol: V11(1). pp 53-62.

**CFC/FAO/ICRISAT.** 2007. Impact assessment study for the CFC-FAO-ICRISAT project: Issues and Methodology. Project Executive Agency (PEA), CFC / FAO/ ICRISAT project ICRISAT, Patancheru

### ***1 B.5 Economic assessment of conservation farming adoption in Zimbabwe (ESA)***

Rationale and Main Objectives: Since 2004, ICRISAT has been providing training and monitoring support to 15 Non-Governmental Organizations (NGOs) promoting conservation farming across 48 districts of Zimbabwe. The central component of the conservation farming package that is being promoted is the planting basin. These are small holes/pits, dug in an unplowed field, where seed is planted. The planting basin is combined with timely weeding in summer and winter, manure and mineral basal and top dress fertilizer application, crop rotation and covering the soil with organic residues. Farmers practicing conservation farming have realized yield advantages over their conventional practices of between 10 and 100%, depending on input levels and seasonal rainfall. These yield increases have led to a rapidly growing number of households trying at least part of the promoted management options of conservation farming.

This study was undertaken in 2007 to better understand socioeconomic factors that influence conservation farming adoption patterns among the smallholder farmers in Zimbabwe. This is also important given that since the onset of the project, there has been evidence of expanded uptake of conservation farming across the country, but with significant variations in what components of the technology to be adopted. This is intended to be the first of planned panel study of the farmers practicing conservation and will assess changes in adoption patterns over time.

Methodology: Towards the end of the 2006/07 cropping season, a survey was initiated across different agro-ecological regions of Zimbabwe to assess the intensity of adoption of conservation farming practices. Data were collected from 232 households from 12 districts that had been practicing conservation farming for at least one season, with extension and input support from 10 different NGOs. Socio-economic data were collected through formal household interviews and focus group discussions.

Milestones and achievements: Since ICRISAT's participation in the promotion of conservation farming in Zimbabwe, there has been evidence of increase in the area under conservation farming, from an average of 0.15 ha in 2004/05 to 0.20 ha in 2006/07 season, with farmers in some districts establishing more than 0.5 ha of basin plots. The changes in plot sizes has been attributed mainly to the positive yield gains across all agro-ecological zones, and can make a major contribution to households food security in Zimbabwe. By 2007 despite being a drought year an increasing number of farmers were able to achieve maize yields of 1,500 kg/ha, and based on these figures, a family of six members may only need a 0.6 ha plot on basins to achieve household food security. An enterprise budget analysis provided evidence that conservation farming is more profitable than conventional farmer practice and these higher returns, including returns to labor input, have also convinced farmers to increase plot sizes under basins. There is also evidence of spontaneous adoption among the farmers who were not initially targeted by the promoting NGOs, but the extent to which this voluntary adoption has taken place across the different agroecological zones could not be quantified by the 2007 survey and requires further study. Also challenges of crop residue application and crop rotation require further research effort.

Major Findings: The most common practices of conservation farming adopted by at least 70% of the households were: basal manure application, topdressing with nitrogen fertiliser, and timely post-planting weeding. The least implemented components were crop residue application (60%), basal inorganic fertilizer application (60%) and crop rotation (28%). The low number of farmers practicing crop rotation was due to limited access to legume seed, preference for cereals, and the common understanding of growing legumes in furrows instead of basins. Although 60% of farmers applied crop residue, in many instances the soil cover was less than the required 30% for effective mulching. Whether fencing is a desirable option to conserve crop residues needs to be entirely seen in the context of the value that crop residues have as animal fodder and needs to be followed up as well.

Based on a Tobit model estimate, there was a strong relationship between experience of conservation farming and the adoption of the various components of conservation farming. Active involvement of both NGOs and the national extension services increased the likelihood of adoption to conservation farming by providing inputs, and backstop advice. Household labor availability and impacts of HIV/AIDS did not limit the uptake of the

conservation farming package, and it could be argued that current NGO initiatives to promote conservation farming to the more vulnerable households in a community as a means of combating food insecurity are justified. Even though the household labour availability did not limit the adoption of conservation farming, the higher labour demand in conservation farming was due to the inexperience of the required steps and it is anticipated that digging basins and weed control will require less and less labour over time. However, this hypothesis needs to be checked in the future.

Profitability analysis showed that conservation farming leads to higher gross margins, higher labor productive gains and a lower production cost compared to conventional farmer practice. The profits from conservation farming are higher than conventional farmer practices across all agroecological regions, even when fertilizer is applied.

Partners: ICRISAT and its partners have implemented 60 training/feedback sessions in the principles of conservation agriculture. These activities have benefited more than 35,000 farm households distributed across the country.

ICRISAT

World Vision

Catholic Relief Services

CARE

Oxfam GB

Save the Children UK

CAFOD

Publications:

**Mazvimavi K, Twomlow S, Murendo C and Musitini T.** 2007. Science in agricultural relief programs: the case of conservation farming in Zimbabwe. Paper presented at the 2nd African Association of Agricultural Economist conference 20-22 August 2007, Accra.

**Mazvimavi K, Twomlow S, Belder P and Hove L.** 2007. An assessment of the sustainable uptake of conservation farming in Zimbabwe. Global theme on Agroecosystems Report. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

**Mazvimavi K, Twomlow S and Minde IJ.** Forthcoming. Intensity of conservation farming adoption in Zimbabwe.

**Mazvimavi K and Twomlow S.** Forthcoming. Conservation farming for agricultural relief and development in Zimbabwe. Book chapter in No-till farming systems (Special Publication III of the World Association of Soil and Water Conservation).

### ***1.B.6 Early adoption of modern groundnut varieties in West and Central Africa (WCA)***

Project Rationale: Groundnut production has suffered major setbacks from groundnut rosette epidemics and foliar diseases, aflatoxin contamination and lack of sufficient and consistent supply of seed of improved varieties in WCA. This has significantly affected productivity and thus production and subsequently led West Africa to lose its share in the domestic, regional and international markets. To regain its competitiveness, groundnut yield would have to increase substantially, using yield enhancing technologies including varieties tolerant or resistant to biotic and abiotic stresses.

The major constraints facing the development of the groundnut sector in West Africa are known to be, among others, the poor access and availability of high yielding groundnut varieties resistant to the rosette virus and foliar diseases. Since the 1990s, ICRISAT and partners – Institute for Agricultural Research (IAR), Institut d’Economie Rurale (IER) and Institut National de Recherche Agronomique du Niger (INRAN) – have developed or introduced a range of groundnut varieties with various attributes including different maturity groups resistant to groundnut rosette disease, foliar diseases and other desirable agronomic traits. About 39 varieties have been selected from regional variety trials across a range of agro-ecological zones.

In 2003 and 2004, the crop seasons were employed under the Groundnut Seed Project (GSP), a large program of more than 200 Farmer Participatory Variety Selection (FPVS) trials in Nigeria, Niger and Mali. Following the choice of varieties by farmers, ICRISAT and partners initiated and catalyzed the development of institutions and



institutional arrangements that will deliver seed at low transaction costs to smallholder farmers. Research institutions were involved in the production of breeder and foundation seed using revolving fund schemes, a process that involved more than 30 farmers' associations and led to 20 small-scale farmers being trained in seed production and marketing.

This resulted in the production of more than 33 tons of breeder seed and 107 tons of foundation seed. In addition, more than 130 tons of certified seed have been produced by community based organizations. This amount of seed could cover more than 100 000 ha of groundnut area. However, we are still learning about whether the modern varieties have spread beyond the FPVS participants and the pilot sites, whether the area cultivated to modern varieties has increased in the pilot sites, whether the number of households using modern varieties have increased, what the major drivers are in the uptake of modern varieties and the options of scaling up and out such technical and institutional interventions.

This study has therefore three main objectives. The first was to assess the level of adoption of modern varieties and compare it with baseline information in the pilot sites. The second was to identify the determinants of uptake and intensity adoption of modern varieties and the third was to propose options for scaling up and scaling out successful interventions.

**Approach and methodology:** The study was carried out in pilot sites from November 2006 to February 2007 in Mali, Niger and Nigeria where GSP started its activities in 2003/04. These regions encompassed the Sahelian and Sudanian-savanna zones. In each country, 75% of all project sites were selected. Next to every selected project site was a control site (a neighboring village) where GSP did not intervene. In each project site, 15 on-farm trial participants were selected from the population of participants and 10 non-trial participants were selected from the population of non-participants. Finally, 10 households were randomly chosen from the population of households in the comparator villages (ie, the control site). In case the number of on-farm participants was less than 15 farmers, enumerators were asked to survey all on-farm trial participants with the remaining unchanged. The distribution of households selected for on-farm trials as well as the control sites according their participation or non-participation is presented in Table 1. Overall, 1190 households were selected and interviewed in the three countries including 868 households in the project sites and 322 in the neighboring villages. Of the households located in project sites, 450 participated in on-farm trials and 418 were non-trial participants.

**Table 1. Distribution of villages and farmers in GSP pilot and control sites by country**

| Country | Pilot villages |                  | Control villages | Total |
|---------|----------------|------------------|------------------|-------|
|         | Participants   | Non-participants |                  |       |
| Mali    | 122            | 123              | 98               | 343   |
| Niger   | 106            | 167              | 97               | 370   |
| Nigeria | 222            | 128              | 127              | 470   |
| Total   | 450            | 418              | 322              | 1190  |

Source: ICRISAT/NARS Survey, 2006/07.

Data was collected at household and plot levels using structured survey questionnaires. Survey questions included modules on (1) socioeconomic and demographic profile of the households, (2) diffusion mechanisms pathways including knowledge of varieties and sources of first information and adoption and dis-adoption of groundnut varieties; (3) use of modern varieties at plot level, (4) diffusion pathways of modern varieties, (5) utilization, consumption and commercialization of groundnut, (6) household transactions, (7) household perception of modern varieties relative to local varieties, (8) farmers' estimate of losses due to GRD in Nigeria and foliar diseases in Niger and Mali and finally (9) households' perception of changes in welfare resulting from the use of modern groundnut varieties.

**Major findings:** Seventeen varieties were used by farmers in the pilot sites of the three countries out of the 39 varieties tested. Uptake has increased significantly during the last three years partially as a result of project intervention. The proportion of area planted with modern varieties has increased by 22% in Nigeria, 12% in Mali and 10% in Niger in the pilot sites since 2003. Farmers using modern varieties have derived significant yield gains of 24%, 43% and 31% over the local varieties in Mali, Niger and Nigeria respectively. The modern varieties had significantly lower per unit cost of production estimated to 9.8%, 11% and 11% in Mali, Niger and Nigeria, respectively. The net income derived by adopters is 66% higher than non-adopters in Mali, 73% in Niger and 111% in Nigeria. Relative to household types, income gains are estimated to be less than 20% compared to poor households in Mali, while it is more than 50% in Nigeria.

Results from the Logit models indicate that the major determinants of adoption in the three countries include the participation of farmers in on-farm trials, the build up of social capital through the empowerment of farmers' associations and small-scale farmers for producing and marketing seed. Constraints to adoption remain the poor access and availability of seed of modern varieties, pest and disease pressure in at least two out of three countries. Tobit results indicate that intensification of modern varieties is dependent essentially on seed availability, social capital, exposure to the varieties through farmers' participatory variety trials.

Two essential drivers of adoption of modern groundnut varieties in West Africa were identified. These include: a) policies and institutional innovations that enhance the opportunities of farmers to experiment (on-farm trials and demonstrations) with varieties and select those with preferred traits; and b) development of village seed supply and delivery schemes.

Partners:

The major partners were West African NARS, IAR, IER and INRAN

Publication:

**Ndjeunga J, Ntare BR, Waliyar F, Echekwu C, Kodio O, Kapran I, Diallo AT, Hassane BY and Da Sylva A.** Forthcoming. Early adoption of modern groundnut varieties in West Africa. Chapter *in* Development of Sustainable Groundnut Seed Systems in West Africa (Ntare, Ndjéunga and Waliyar eds.). Proceedings of the final workshop, 2-3 July 2007, Bamako, Mali. Bamako Box 320, Mali: International Crops Research Institute for the Semi-Arid Tropics.

***1.B.7. Farmer participatory evaluation and dissemination of improved groundnut varieties in West Africa (WCA)***

Rationale: Over the last 25 years, a range of varieties has been developed, tested and adapted in West and Central Africa. Thirty-nine were found adapted according to Mayeux et al. (2003). However, resource-poor farmers seldom have access to such new varieties that may improve their livelihoods. Many farmers still grow old varieties and hence fail to benefit from the most modern products of crop improvement. One of the reasons for the low adoption of new varieties is that farmers have little exposure to new varieties, or the varieties do not satisfy their preferences and needs. Thus, farmers need to test a range of varieties under their own conditions, resource levels and environment in order to select the ones they prefer. Farmers' participation in technology generation and selection as drivers to adoption are well documented (Ashby 1991; Sperling et al. 1993). FPVS has shown successes in identifying varieties preferred by farmers, and accelerated their dissemination (Joshi and Witcombe 1996; Witcombe et al. 1996; Mulatu and Belete 2001; Mulatu and Zelleke 2002).

The demand for varieties by farmers and oil processing industries is a result of plant, seed and other desirable traits that are embodied in the varieties. Knowledge of the range of plant, seed and processing traits are valuable for crop improvement programs and good market signals for processors (Ndjeunga et al. 2003). The demand for improved groundnut varieties will increase if varieties are designed to include producer and consumer preferred traits. Therefore, improving the performance of varieties accounting for all significant traits will contribute to the productivity and profitability of groundnut.

Choosing a variety is only half the story. Equally important is to ensure that seed of preferred varieties is accessible, and affordable to end-users. However, in West Africa, the constraints limiting the performance of seed supply systems remain the lack of awareness among farmers about new varieties, poor functional seed and product markets, limited access to seed of new varieties, limited supply of breeder/foundation/ certified and commercial seed (Ndjeunga et al. 2006).

The objectives of the present study were: 1) to identify farmers' preferred traits and varieties through FPVS and 2) to test a range of seed multiplication and delivery schemes.

Approach and methodology (Mother and baby trial approach):

*The trial designs:* The mother and baby trial design was used as the main participatory tool in the evaluation and selection of varieties. These are single-replicate designs used to assess the relative performance of varieties. In mother trials many entries are grown together in the same field. The trials are researcher-designed but farmer-managed, and they are replicated across villages. They not only serve as demonstration plots or focal

points for discussion but are also specifically designed to provide quantitative analyzable data on yield (Snapp 2002) and farmers' preference for traits embodied in the varieties.

Trials were set up in a randomized complete block design of five varieties and five replications. Plot size for each variety was 10 x 10 m per replication. Farmers were selected by the village chief, or farmers' associations implemented these trials collectively. During the vegetative cycle, two assessments were carried out with farmers at flowering and another at the harvesting period. At harvest a preference survey was conducted involving 25 farmers.

In the baby trials, only farmers' perceptions on yield were collected. A farmer grows 1 to 3 new varieties along with the local variety under traditional management practices. Replication is across farmers, either in the same village or across villages. In 2003 crop season, 144 FPVS trials were established in 45 locations across the four countries. In 2004, the trials were increased to over 200.

*Variety preference assessment:* The development of a survey instrument for variety preference involved a number of steps. The available literature was reviewed to develop a list of important groundnut plant and seed characteristics for potential inclusion in the questionnaire. Germination, plant type, disease resistance, flowering, shape of leaves, maturity, pod and haulm yields, pod filling sizes of pod, seed, color were often cited as important plant and seed characteristics. Based on potential characteristics likely to explain choice for varieties, a participatory rural appraisal (PRA) was held with groundnut producers in the three villages in order to evaluate alternative question formats, contents and elicit general advice from consumers for different traits. The last stage in the process involved the development of the survey instrument. Only characteristics that were ranked high via the focus-group meetings were included in the questionnaire. Accordingly, 16 plant and seed characteristics were included. Respondents evaluated the five groundnut varieties using a five-point preference scale (0 being the least preferred and 4 being the most preferred) using the 16 criteria.

*Building seed supply and delivery systems:* After varieties that are preferred by farmers or required by the market have been selected, access to seed becomes a major constraint to uptake. Thus, a range of institutions and institutional arrangements were tested to identify the best strategies involved in seed production and delivery to ensure a sustainable supply of high quality seed at affordable prices.

*Assessing the performance of FPVS pathways:* Baseline surveys were carried out in pilot sites in 2003 to assess households' resource endowments (natural, physical, human, economic and financial capital and social capital) at project inception. In addition, the seed supply schemes were assessed. At the end of the project in 2007, a survey was carried out to assess the level of uptake of varieties through the different alternative arrangements. Pilot sites were randomly selected. Within pilot sites, farmer participants in the FPVS trials were randomly selected and non-participants were selected using a list of households provided by the chief of villages or developed by enumerators. Control sites were considered in neighboring villages where the project did not intervene.

Information was collected on farmers' socioeconomic profile (age, gender, education and family size); the institutional and infrastructural environment (access and availability of seed of preferred varieties and markets), technological constraints, plant type, cycle, seed size and color, utilization (oil, edible, confectionary, fodder for livestock) and resistance to foliar diseases were hypothesized to be the main constraints to uptake of modern groundnut varieties and factors explaining farmers' variety preferences. A simple system of mean and median ranking was used to assess farmers' preference for varieties.

**Major findings:** Thirty-nine improved varieties (released and pre-released) from ICRISAT and National Agricultural Research and Extension Systems (NARES) partners were evaluated in over 200 FPVS on-farm trials in 45 locations in Mali, Niger, Nigeria and Senegal. The objectives were to identify farmers' preferred traits and varieties and test a range of seed multiplication and delivery schemes. The farmers evaluated the different varieties under their own management practices and resources.

*Preferred traits included:* early maturity, high pod and fodder yield, resistance to diseases, seed color, taste, oil content, tolerance to drought and marketability. Preference often differed among the sites, which reflected differences in agro-ecological zones. In each location farmers selected at least two improved groundnut varieties based on some of these traits. Overall five varieties (Waliyartiga [ICG 7878], Fleur 11, JL 24, ICG [FDRS] 4 and Mossitiga) were selected in Mali; four (ICG 9346, RRB, J11 and T 81-73) in Niger; three (SAMNUT 21, SAMNUT 22 and SAMNUT 23) in Nigeria and five (ICGV 86124, ICGV 89063, PC 79-79, H 75-O and 55-33)

in Senegal. Industrial testing showed that the varieties had oil content above the local check 47-10 in Mali and 55-437 in Niger.

After two years of evaluation, more than 30 farmers' associations and small-scale seed producers were involved in seed production and distribution. More than 150 tons of seed of different classes that could cover 100,000 hectares were produced. About 74% of the farmers in pilot areas are using modern varieties, and about 67% of the groundnut area is planted with them. In locations where FPVS was limited to providing only seed for experimentation without ensuring seed supply such as in Mande and Dioila in Mali, the proportion of the area covered with improved groundnuts was low (28%), whereas in locations where FPVS was implemented in conjunction with setting up institutions and institutional arrangements to supply seed to farmers (such as in Kolokani, Mali), the uptake in areas around the pilot sites was estimated at 83%.

Partners:

NARS

NGO

Farmers' associations

Small-scale farmers

Publication:

**Ntare BR, Ndjeunga J, Waliyar F, Kodio O, Echekwu CA, Kapran I, Da Sylva A, Diallo AT, Bissala HY and Sako K.** Forthcoming. Farmer participatory evaluation and dissemination of improved groundnut varieties in West Africa. Chapter *in* Development of Sustainable Groundnut Seed Systems in West Africa (Ntare, Ndjeunga and Waliyar eds.). Proceedings of the final workshop, 2-3 July 2007, Bamako, Mali. Bamako Box 320, Mali: International Crops Research Institute for the Semi-Arid Tropics.

***1.B.8 Groundnut adoption study in Uganda (ESA)***

Groundnut is a widely grown legume across eastern and southern Africa. It is highly tradable in local and international markets, making it a valuable source of cash for dryland farmers. It is also consumed in different forms and improves nutritional and food security for the family. It offers a nutritious diet - rich in proteins, fats, and oils while the byproduct is used as livestock feed.

One of the limiting factors for farmers is that local groundnut varieties are susceptible to diseases, especially rosette. The disease reduces yields and marketable surplus and hampers commercialization. In Uganda, Soroti Agricultural and Animal Research Institute (SAARI) developed four rosette resistant varieties from groundnut breeding materials received from ICRISAT Malawi. The varieties are being promoted and up-scaled through the National Agricultural Advisory Services (NAADS), which has led to accelerated uptake and diffusion. This study highlights the adoption and impact of the new groundnut varieties in Ugandan counties.

Project objectives:

- Assess the spread and intensity of cultivation of improved groundnut varieties
- Identify the factors that condition the uptake of improved groundnut varieties
- Assess the impact of improved groundnut varieties on the adopting households

Project outputs:

- Adoption and impacts of improved groundnut varieties in Uganda documented
- Policy recommendations on the enhancing and up-scaling of the use of improved groundnut varieties in Uganda

Methods: Household and group level data was collected to ascertain the extent of spread, intensity and impact of improved groundnut varieties in Uganda. A large-scale joint field survey was conducted in 2006 covering seven groundnut growing districts and 945 smallholder farmers. This was coordinated by ICRISAT, but NAADS led the survey with the participation of NARO scientists. Standard statistical methods ranging from basic descriptive statistics and advanced econometric models were fitted on the data to address the intended study objectives.

Milestones:

- Data collection at both household and group level was successfully completed
- Data entry and cleaning has been completed

- Analysis is underway
- Poster presentation prepared from preliminary results

Preliminary findings: The improved varieties have been adopted widely in Uganda. More than half of the farmers adopted at least one improved variety; in the seven districts studied about 200,000 farmers have adopted new varieties. Serenut 2 is the most widely adopted variety. Over half, the groundnut area is planted with improved varieties. Compared to locals, improved varieties provide about 40% yield advantage and almost triple the net income of farmers. Adopters produce 57% more than non-adopting farmers and consume more groundnuts on-farm than non-adopters. Adopters generate higher marketable surplus (65% more) than non-adopters. The higher level of adoption can be attributed to:

- Good economic attractiveness of new varieties to farmers
- Increased awareness of farmers about the new varieties
- Involvement of NAADS and other partners in seed production, marketing and distribution
- Participation of communities in local seed production
- Need to strengthen local seed supply, output marketing and credit services to further expand technology uptake.

An econometric analysis of the data is underway and the draft paper is expected by the end of the year.

Partners:

ICRISAT  
NAADS  
NARO

Publications:

**ICRISAT.** 2007. Pigeonpea technology adoption and impact in Kenya and Tanzania. Poster paper prepared for the ICRISAT Governing Board meeting in Lilongwe, Malawi, 22-25 Oct 2007. **International Crops Research Institute for the Semi-Arid Tropics**

**Shiferaw B, Okello J, Kebede T, Muricho G and Okecho G.** 2007. Adoption of improved groundnut varieties in Uganda: Economic benefits, key determinants and constraints to technology diffusion. Draft working paper, Nairobi, PO Box 39063. Kenya: International Crops Research Institute for the Semi-Arid Tropics.

***1.B.9 Pigeonpea adoption study in Tanzania and Kenya (ESA)***

Pigeonpea (*Cajanus cajan*) is an important grain legume widely grown and adapted to the semi-arid regions of South Asia and Eastern and Southern Africa. The largely drought-tolerant crop allows poor families protect their livelihoods and meet their food and cash income when most other crops fail in areas with erratic rainfall. Farmers in land-scarce areas can intensify land use and harvest two crops through intercropping with cereals (like maize and sorghum) allowing farmers to diversify risks and maximize their incomes. The biomass can be used for feeding livestock or as source of firewood, thereby reducing the burden on women and children and reducing deforestation and loss of biodiversity. Pigeonpeas are tradable crops both in local and international markets, and export demand (mainly to south Asia) often outstrips supply. Smallholder farmers market a substantial portion of the annual produce to meet their cash requirements. Kenya and Tanzania are one of the major growers and exporters of the crop in the region. Tanzania exports significant amounts (30-40 thousand t/yr) to India, and there is a growing processing and value-adding industry that would allow the country export de-hulled split pea (dhal) to the Far East, Europe, and the Americas.

However, the pigeonpea industry in Tanzania and Kenya has been affected by poor productivity and limited marketed surplus produce of smallholder farmers. The poor yields are mainly due to low yielding and disease susceptible local varieties. Farmers even abandoned production of this important crop mainly due to Fusarium wilt, a fungal soil-borne disease that devastates the crop. ICRISAT with partners has developed two Fusarium-resistant improved pigeonpea (FRIP) varieties that embody farmer and market-preferred traits and is becoming popular in northern Tanzania and eastern Kenya. Farmers however face seed access constraints that limit the quick spread of the technology to wider areas.

Methods: Using empirical data from the pigeonpea growing regions where the technologies were initially tested and promoted, this study estimates the level of technology adoption and analyzes the key determinants of variety adoption and the overall economic benefits. Unlike many previous adoption studies, technology adoption is modeled using a double-hurdle model, which considers technology adoption conditional on farmer access to



new seeds and takes into account the thresholds that smallholder farmers need to overcome at different stages before actual adoption takes place. This improves the consistency of the parameter estimates. The economic surplus to Tanzania is estimated using IFPRI's DREAM model.

Main objectives:

- Assess the breadth and depth of adoption of improved varieties
- Identify the policy relevant factors influencing the adoption of improved pigeonpea varieties and quantify their influence
- Assess the potential economic and social impacts of improved pigeonpea varieties for adopting farmers as well as producers and consumers

Project outputs:

- Research report on the level of technology uptake and policy relevant constraints
- Policy recommendations on how to enhance improved pigeonpea varieties uptake and thus impact and scaling up made

Milestones:

- Data collection was successfully completed
- Data entry, cleaning and analysis completed
- Working papers, conference papers and journal papers finalized

Major findings: Despite the high potential of pigeonpea in Tanzania, its productivity had been limited due to the devastating disease, fusarium wilt, caused by soil borne fungus. The disease causes up to 50% productivity loss. By the early 1990s, ICRISAT had realized this problem and started a breeding program, which resulted into the release of fusarium resistant pigeonpea varieties by the mid 1990s. Adoption spread of these fusarium resistant pigeonpea varieties stood at 34% by the year 2004 and was projected to reach 60% by the year 2007. The intensity of adoption (pigeonpea area under improved varieties) stood at 30% while economic benefits from adopting new varieties were estimated at 80%. Access of seed from informal channels and farmer-to-farmer technology transfer was not sufficient to spread the varieties widely. More effort in terms of strengthening the institutional architecture for effective technology dissemination is therefore needed to accelerate the adoption process.

On the other hand, by the year 2005, adoption spread of improved pigeonpea varieties in Kenya stood at about 55% while adoption intensity was at 50%. Adoption intensity increased as farmers adopted and adapted new varieties to their economic and biophysical settings. Farmers plant at least 50% of the pigeonpea area with improved varieties, indicating a high intensity of adoption. Over the last five years, over 23 tons of seeds of improved pigeonpea varieties have been distributed to farmers in eastern Kenya. Over 12 tons of medium and long duration pigeonpea seed reached farmers during 2005-2007 through the Lucrative Legumes Project supported by USDA. More than 14,000 farmers are expected to have accessed improved seeds.

Partners:

ICRISAT  
SARI  
TechnoServe  
DANIDA  
USDA

Publications:

**ICRISAT.** 2007. Pigeonpea technology adoption and impact in Kenya and Tanzania. Poster paper Prepared for the ICRISAT Governing Board meeting in Lilongwe, Malawi, 22-25 Oct 2007. International Crops Research Institute for the Semi-Arid Tropics.

**Shiferaw B, Obare G and Muricho G.** Forthcoming. Rural market imperfections and the role of institutions for collective action to improve markets for the poor. CAPRI Book Chapter.

**Shiferaw B, Kebede TA and You Z.** Under review. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. Journal of Agricultural Economics.

### ***1. B.10 Assessing impacts of sustainable land management programs on land management and poverty in Niger (WCA)***

**Rationale:** Poverty, low agricultural productivity and land degradation are severe problems in Niger. Niger is one of the poorest countries in the world, ranking at the bottom of 177 nations in terms of its human development index (UNDP 2006). Almost 85 percent of the country's population lives in rural areas, most of them with incomes well below the poverty line. Ninety percent of the labor force is employed in agriculture, which is predominantly subsistence-oriented, dependent upon the dry and drought-prone climate and mostly sandy soils, and focused on production of a few basic food crops (mainly millet, sorghum and cowpeas) and livestock. Low, erratic rainfall and overexploitation of natural resources due to rapid population growth (3.3% per annum) and other factors have contributed to declining availability, productivity and biodiversity of vegetation in both rangelands and cultivated areas. This has reduced the capacity of rural households to cope with cyclical droughts and locust invasions, and increases their vulnerability to food insecurity. Consequently, sustainable management of productive natural resources, particularly land and water, is essential for Niger to achieve sustained growth in agriculture and reduced rural poverty.

Recognizing the need for concerted action to address the structural causes of these problems, the Government of Niger is implementing a broad rural development strategy, which includes several components related to natural resources management. The government and its development partners are implementing projects promoting land rehabilitation and sustainable land management (SLM). More than 50 government, donor and non-government organization (NGO) SLM programs have been implemented in Niger since the early 1980s. Furthermore, many communities and households are pursuing land rehabilitation activities on their own initiative. According to one recent study, at least 3 million hectares of land have been rehabilitated through farmer managed natural regeneration of trees and other vegetation, and some 250,000 hectares have been rehabilitated through application of soil and water conservation (SWC) measures such as *zai* (also called *tassa*), *demi-lunes*, and stone bunds (Adam et al. 2006). That study estimated that most of these community and household efforts have high rates of return, and concluded that they are contributing to many economic, social and environmental benefits, including improvements in food production, food security, improved groundwater recharge, increased availability of fodder resources, reduced time spent collecting fuel wood, and others.

Although the previous study by Adam et al. (2006) provides very important evidence and has attracted considerable attention, many of its conclusions were based on a rapid assessment conducted in a small number of communities (16) selected in a few regions of Niger (Tahoua, Maradi and Tillabery). Only four of the study communities were villages without SLM program interventions, and it is not clear how these villages were selected or how similar they are to the intervention villages in ways other than program interventions. Given the small sample size and lack of attention to assuring that the non-intervention communities were comparable to the intervention communities, it is not clear how well one can attribute differences between the intervention and non-intervention communities as resulting from the program interventions, or generalize from the study findings to other areas of Niger. Recognizing the limitations of this otherwise valuable study, one of the principal authors of the study has argued that more hard evidence is needed, especially on the economic impacts of such investments, to convince policy makers that increased investments in such SLM efforts are economically rational and essential to achieve the Millennium Development Goals (Reij 2006).

The present study seeks to address this critical information need. The main objective was to assess the impacts of SLM programs in Niger, emphasizing impacts on communities' and households' adoption of improved land management practices and the impacts that this has on agricultural production, household income and wealth. We also assessed communities' and households' perceptions of program impacts on a broader set of economic, social and environmental indicators, although this is not the primary focus, and such subjective perceptions are not verified through objective measurements, though this would be a valuable topic for future research. We seek to draw representative conclusions about the economic impacts of SLM programs by characterizing communities and households that are, or are not, participating in such programs and selecting for comparison communities and households that are otherwise similar in observable characteristics.

This study seeks to address the dearth of solid empirical evidence on the economic impacts of SLM programs, not only in Niger but in sub-Saharan Africa (SSA) more generally, by demonstrating methods for conducting such analysis. Although there have been numerous studies of adoption of land management practices and some

(mostly *ex-ante*) studies of the costs and benefits of particular land management practices<sup>1</sup>, studies of the impacts of SLM programs are rare. Of the studies that have been done, most appear to be in the form of unpublished consultancy reports. The authors are not aware of any published and peer-reviewed studies of the impacts of SLM programs in SSA using rigorous empirical methods to assure adequate representativeness of the findings and a proper counterfactual.

Approach and methodology: In this section we describe the methods used to select the regions, villages, and households studied, to collect the data and analyze the data collected. The methods used were selected to maximize the ability to draw robust and generalizable conclusions about the impacts of SLM programs, with substantial attention to identifying suitable counterfactual communities and households and to potential biases.

Selecting the study regions and villages: In order to select the regions and villages where the study would focus, we first assembled a database on all villages in Niger, including information on the geographic location, agro-ecological zone, dominant soil type, population, distance to Niamey and distance to the nearest town of at least 5,000 people, access to a village market, presence of health infrastructure and services, and presence of past or current SLM programs in the village. These data were collected from different secondary data sources, including the village database, which contains information on village infrastructure. They were assembled in a geographic information system, enabling the village locations to be linked to other available geographic data, such as the agro-ecological zone (characterized by range of average annual rainfall and length of growing period) and dominant soil type, and enabling estimation of some variables, such as distance of each village to Niamey and to the nearest town.

The data on presence of programs were collected for 12 SLM programs and projects that have been completed since the early 1980s or are currently ongoing in Niger. It was not possible to collect complete information on every project involved in promoting SLM activities, but the database reflects the largest ones. The completed projects incorporated in the database include Projet Agro-Sylvo-Pastoral (PASP), Projet Intégré Keita (PIK), Projet de Gestion Ressources Naturelles (PGRN), Projet d'Aménagement des Forêts Naturelles (PAFN), and Projet de Développement Rural de Tahoua (PDRT). The ongoing projects include Appui pour la Sécurité Alimentaire par la Petite Irrigation (ASAPI), CARE, Projet d'Appui pour le Développement Local (PADL), Lutte Contre la Pauvreté (LUCOP), Programme d'Actions Communautaires (PAC), (PLCE) and the Special Programme of the President (PSPR). We found these SLM projects operating in fewer than 8% of the nearly 12,000 villages in the database. Very few villages in the arid northern region of Agadez or in the eastern region of Diffa were found to have SLM programs. As a result, we decided to focus on the other five rural regions of Niger where such programs were more common.

Using this database, 72 project villages were selected for the study using a stratified random sample, stratified by region and project type. The program types included in the stratification were LUCOP, PAC, PASP, PGRN, PIK, PSPR, and villages with multiple programs. PGRN, PASP, PIK, and PSPR are the largest SLM programs that have operated in Niger, in terms of the total number of villages affected. PAC and LUCOP were selected as representatives of participatory programs and because they are either a sponsor (PAC) or closely affiliated (LUCOP) with this study. A maximum of four villages was randomly selected from each region by program type stratum to obtain a broad representation of different regions and program types.<sup>2</sup> Where there were less than four villages in a stratum, all program villages in that stratum were selected.

For each program village, we identified a matching non-program village (where no major SLM programs had operated in the past or are currently operating), based on the data assembled in the village database. The matching non-program village was selected from the same administrative region of Niger and from the same agro-ecological zone (based on length of growing period) as the corresponding program village. Within each region and agro-ecological zone, matching villages were found using propensity score matching (PSM) (Rosenbaum and Rubin 1983), using the nearest neighbor method, based on distance to the nearest town.<sup>3</sup> There

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<sup>1</sup> For example, see Barrett, Place and Aboud (2002) and Pender, Place and Ehui (2006) for collections of studies of land management practices and some of their impacts in various contexts of SSA.

<sup>2</sup> The decision to select the sample program villages in this way was made in consultation with officials from PAC and other stakeholders, and represented a compromise between obtaining more representation of programs that operated in a larger number of villages, and obtaining a broader representation of programs in different regions. Stratifying only by program type would have resulted in much more of the sample being in Tillabéri and Tahoua, particularly if sampling proportional to numbers of program villages had been used.

<sup>3</sup> We did not use the other data in the database (eg. distance to Niamey, population density, soil type, access to markets or health infrastructure) in the PSM procedure. Distance to Niamey is largely reflected by matching

were 71 matching non-program villages (one matching non-program village was the best comparator for two different program villages), resulting in a total target sample of 143 villages. Of these 143 villages, surveys were not conducted in four, due to problems of inaccessibility in some cases, and in some cases because what were originally classified as non-program communities turned out to have a SLM program operating and were not surveyed. The resulting sample therefore included only 139 villages.

Selecting the sample households: Within each program village, a listing of program participants and non-participants was made in consultation with village leaders. Six program participants and six non-participants were randomly selected for inclusion in the household survey. In non-program villages, six households were randomly selected. Of the potential sample of 1254 sample households (840 in 70 surveyed program villages and 414 in 69 non-program villages), 1218 were actually surveyed. The reduction in number of surveyed households was partly due to the fact that in some program villages there were few participating or non-participating households, and because of unavailability or unwillingness of some respondents to participate.

The reason for selecting these three groups of households is that non-participants in program villages may be indirectly affected by the presence of the program.<sup>4</sup> For example, knowledge about SLM technologies may be shared between program participants and non-participants, or non-participants may benefit from community level investments in land management, infrastructure or other measures. Households in non-program villages are expected to be much less affected by such spillover effects, especially because such a small percentage of villages are affected by programs (though some spillovers may still occur to non-program villages, particularly in regions where program involvement is dense). Comparisons between program participants and comparable non-participants within program villages reflect the direct impacts of program participation, while comparisons between comparable non-participants in comparable program vs. non-program villages reflect the spillover impacts on non-participants in program villages. Comparisons between program participants and comparable households in comparable non-program villages reflect the total impact of the program, considering both direct and indirect spillover effects.

Of course, the households in these three sample groups may not be comparable, even though they are randomly selected, because the decisions by programs to operate in particular villages and the decisions of households about whether to participate in the programs are likely not random. This can lead to serious biases in evaluating the impacts of programs (Heckman et al. 1998), and is the reason for using the matching and econometric analytical methods discussed below.

Data collection and management: Surveys were conducted at both the village and household level in the selected villages. At the village level, a group of usually ten to fifteen respondents was assembled, representing village leaders as well as people of different genders, ages, occupations and social status in the village. The village questionnaire asked questions about access to markets, infrastructure and services, programs and organizations operating in the village, local prices of inputs and outputs, land tenure systems, and management of village common lands, including the costs and returns to any investments made in the common lands, institutional arrangements for managing such resources, and perceptions of changes in resource and welfare conditions and the reasons for change.

The household survey was conducted usually with the head of household. It collected information about household demographic characteristics and endowments of physical, human, natural (land), financial and social capital, plot tenure and quality characteristics, and plot-level land management decisions, investments, inputs and outputs, sources of information about land management technologies, household participation in community land management activities, and households' perceptions of changes in welfare and resource quality indicators and the reasons for change.

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within administrative regions. Since the data on population density were at the regional level, variations in measured population density were also reflected by matching within regions. We were not sufficiently confident about the quality of the soil type data to use it as the basis for matching, and in any case not much variation in soil types between program and non-program villages for most programs was evident. There were few villages that had a market or health infrastructure in the village, and access to health infrastructure was judged to be of limited relevance to SLM decisions.

<sup>4</sup> This approach is similar to that used by Feder et al. (2004) in their evaluation of the impacts of Farmer Field Schools in Indonesia.

The data were entered into databases and intensively checked for data entry errors, out of range values, inconsistencies and outliers. The data analysis has been conducted using the cleanest possible data set, although there still may be reporting and measurement errors in the data. Robustness checks and alternative statistics (eg, reporting medians as well as mean values and standard errors) were used in the data analysis to address concerns about remaining errors.

Data Analysis: Analysis of the data included use of simple descriptive statistics, matching methods, stochastic dominance analysis, multivariate econometric methods, and methods of economic cost benefit analysis to estimate rates of return and net present values of investments.

Major findings: We find that SLM programs have been, or are operating in fewer than 8% of the villages of Niger, have been heavily concentrated in a few regions (especially Tillaberi and Tahoua), are more common closer to Niamey and to towns, and are more common in more favorable rainfall zones, though there are differences in these tendencies across programs. Within program villages, households participating in most SLM programs (except PGRN) tend to be wealthier than non-participants, are more likely to be female-headed, and for some programs, participant households tend to be younger, have fewer adult members, and have fewer out-migrants.

Using matching and econometric methods to control for such differences between villages and households that participate in SLM programs, as well as differences between plots, we find that SLM programs have promoted significantly greater adoption of several land management practices at the village and household/plot level, including establishing tree plantations, protected areas for natural regeneration, and construction of soil and water conservation (SWC) measures at the village level, and use of several land management practices at the household level. The economic impacts of village tree plantations and protected areas are quite favorable on average, with a mean estimated internal rate of return of at least 28% for tree plantations and more than 200% for protected areas. Furthermore, tree plantations increase average household wealth by about 7% on average. However, there is wide variation in returns to individual investments, with most yielding zero estimated current benefits in the survey year.

At the national level, we estimate that tree plantations promoted by SLM programs, which have planted more than 65 million trees in total, have a net present value of increased economic benefits (mainly from increased fodder production) and increased value of tree stocks of as much as 144 billion FCFA. This compares favorably with the total cumulative cost of SLM program activities in Niger, which we estimate to have been about 70 billion FCFA for 31 projects that were reviewed (estimated as one-third of the total costs of these programs, since many other activities not related to SLM have also been promoted by these programs). The estimated national level impact of program-promoted community protected areas appears to be much smaller, primarily because much fewer communities appear to be adopting such areas as a result of program interventions.

The economic impacts of several of the household level land management practices are favorable but not dramatic, with zai, organic and inorganic fertilizer use all contributing to higher crop production by about 20 to 30% on average, and stone bunds reducing the risk of low production. Considering the costs of these practices, we find that zai are not profitable on average, but that organic and inorganic fertilizer use is marginally profitable. Consistent with these findings, we find insignificant impacts of most programs on the value of crop production and household income, except a surprising negative impact of participation in PAC and PGRN on crop production. Further investigation into why this negative impact is seen, whether it is only a near-term phenomenon, and what could be done to address it is needed.

Although the economic impacts of household level participation in SLM programs are limited, most participating households and communities report favorable perceptions of the programs and land management practices promoted on a wide range of social, environmental and economic indicators. Although such reported perceptions may overstate the benefits of programs, the results suggest that important benefits are occurring that are not reflected in the estimated economic returns. Further research on this topic would be useful.

Publication:

**Pender J and Ndjeunga J.** 2007. Assessing impacts of sustainable land management programs on land management and poverty in Niger. Paper presented at the workshop on Monitoring and evaluation and impact assessment of land management programs in Niger, 18-19 October 2007, Niamey, Niger. BP 12404, Niamey, Niger: International Crops Research Institute for the Semi-Arid Tropics.

## **Priority 5B: Making international and domestic markets work for the poor**

Priority 5B, Specific goal 1: Enhanced livelihoods and competitiveness for smallholder producers and food safety for consumers influenced by changes in national and international markets

Priority 5B Specific goal 2: Improved marketing environment for smallholders by improving the efficiency of domestic markets

**Output 1C. Strategies that encourage investment in dryland agriculture, that enhance the competitiveness and quality standards of farmer products, that facilitate innovative methods to improve coordination in market chains, that ensure profitable marketing channels and outlets for ICRISAT mandate crops in domestic and international markets identified and promulgated by 2009 throughout the SAT with new knowledge shared with partners**

*MTP Output Target 2007 1.3.1*

*Strategies that enhance farmer access and utilization of productive inputs and linked services that enhance competitiveness promoted*

### ***1.C.1 Chickpea competitiveness and market study in Ethiopia (ESA)***

**Background:** Chickpea is a high-value crop that is adapted to deep black soils in the cool semi-arid areas of the tropics, sub-tropics as well as the temperate areas (eg, Canada and Australia). Despite its high potential for improving the incomes of the rural poor, the crop has not been fully exploited. Several factors have contributed to this. First, the available high-yielding varieties with market-preferred traits have not reached farmers and hence, the productivity of the crop has remained to be one of the lowest in the world. Second, the local landraces grown by farmers in many countries do not meet the quality and quantity requirements preferred by domestic and international markets. This means that chickpea produced by small-scale farmers is limited in volume and quality, making it less tradable in international and regional markets and largely consumed on the farm. In Ada-Liben district, where a number of primary cooperatives have emerged and farmers have been contracted to multiply seeds, less than 5% of the farmers in 2004/05 used improved and market-preferred chickpea varieties. Insufficient seed production and marketing systems that limit availability of quality seeds of improved varieties to smallholder farmers is a major limiting factor for the limited uptake of new varieties, especially the Kabuli types. The other limiting factor often stated by farmers in Ada-Liben district is widespread theft during the green stage and lack of credit for farmers to buy the improved seeds. The credit constraint may not be a major factor for some better off farmers but may particularly be important for poor households as improved seeds are invariably priced higher than the grain and chickpea seed requirements exceed 100 kg/ha, especially for large-seeded varieties. In order to create enabling and conducive conditions for the uptake of profitable varieties, there is a need to enhance farmer access to essential input (including credit) and output markets and information about complementary chickpea technologies.

Given the low yields, the marketed surplus is small and most of the Ethiopian chickpea is traded domestically. In recent years, Ethiopia's export of Desi chickpeas has been growing partly due to adverse growing conditions in Australia (*Ascochyta* blight) and droughts in South Asia. The markets are usually characterized by small volumes, high transactions costs, lack of grading and quality control systems, and severe lack of market information, especially for export demand and prices.

**Project objectives:** This study reviews the existing conditions in relation to production and marketing of chickpeas and outlines the major technological and institutional constraints for harnessing market opportunities in the chickpea sub-sector. This is enriched through analysis of variety introduction, market conditions and seed delivery systems in Ada-Liben district, one of the major chickpea growing districts in the country where new market-preferred and high-value Kabuli types are being tested and promoted. The study aims to assess the overall competitiveness of chickpeas, the structure and functioning of existing markets and contribute to policy discussions on market oriented agricultural Progress as a means for achieving improved and sustainable livelihoods for the rural population

#### **Project outputs:**

- Chickpea marketing chains in light of emerging opportunities and capacity building needs analyzed

- Existing and emerging seed supply systems assessed including recommendations for improvements and capacity building
- Performance of chickpea production systems based on newly introduced Kabuli types evaluated and recommendations for improvements made

Methods: Informal and formal approaches to generate both quantitative and qualitative data were used ie, extensive consultation with private and public sector enterprises and research organizations as well as a survey of the market chain for chickpeas were conducted. This was complimented with farmer group discussions and key informant surveys. The structure and functioning of chickpea markets was investigated using Ada-Liben district as the focal reference point in tracing the relevant marketing channels and actors involved, prices and transaction costs in the chickpea marketing system. A survey was conducted along the value chain that links producers in the primary markets with domestic consumers and exporters in tertiary markets (Addis Ababa and Nazareth). As key marketing reference points, nine major rural markets in the district were identified and included in the survey. At the secondary market level, the survey included several wholesalers (including the EFU) and retailers in the district town (Debre Zeit). The survey extended to the major markets linked to the district and included Addis Ababa and Nazareth as tertiary chickpea markets.

In each of the identified markets along the marketing chain, information was collected using a formal survey instrument from March to June, 2006. Trained enumerators administrated the survey of assemblers, retailers, and wholesalers in the primary and secondary markets in Ada-Liben district, while trained economists collected the information from exporters, processors, supermarket and others in the tertiary markets. The survey instrument was specially designed to track the alternative channels used in chickpea transactions and to capture the associated prices, volumes, and transaction costs in the source and sink markets along the value chain. Data collected included information on chickpea marketing operations, the number and relative importance of various participants in terms of volume of flow; the profile of market participants and the level of their participation; the flow of information on production and market conditions; the degree of partnership and relationship between buyers and seller; frequency of transactions; the points of transaction in grain buying and selling; quantity and quality of the traded grain or product; seasonality of transactions; the cost of grain handling, cleaning and processing; marketing costs and margins; and information on perceived strength and weakness of the chickpea business operation. In addition to this primary data, the study uses field visits and qualitative data collected from traders through informal discussions and secondary information gathered from alternative sources. Marketing costs were taken to include both transaction costs and standard marketing costs (eg, transport, assembly, grading/sorting). Measured transaction costs included the reported costs of finding a buyer/seller, costs of monitoring/inspecting the quality of grain being traded, and the costs of negotiating prices and ensuring quality standards and agreed volumes. The standard marketing costs considered in this study included the costs of assembling the produce, grading/sorting, transportation, and storage, among others. Lack of detailed data prevented us from computing each of these costs separately.

Milestones:

- Data collection and analysis completed
- Working papers published

Major findings: The small seeded red colored desi type chickpeas are the widely grown varieties in Ethiopia. They are exported especially to South Asia. However the newly introduced and well adapted large seeded white colored Kabuli types have a large market in Europe, North America, South Africa and even the Middle East markets. Thus, interventions to enhance competitiveness and market responsive seed supply and input delivery system is required in order to harness this opportunity and tap its potential. Chickpea marketing system is characterized by low volumes, scattered and fragmented suppliers, complex supply chains, lack of reliable sources of market information, lack of quality control and grading system and high transaction costs. With low yields and high transaction costs, a large proportion of the produce is traded in the local markets. Future market contracts are needed to provide reliable market outlets so as to increase demand for improved variety seeds. Farmers and Unions need to know about the production costs and prices in the international markets for them to make an informed decision on pricing. Prices for both Kabuli and Desi types have been on the rise in the recent past with Kabuli generally fetching a higher price than Desi thus making economic sense for farmers to shift from Desi to Kabuli production. Future market contracts are constrained by lack of trust between farmers and traders.

The chickpea marketing system is generally characterized by low volumes, scattered and fragmented suppliers, complex supply chains, lack of reliable sources of market information, lack of quality control and grading

systems and high transaction costs. In a country that is landlocked and does not have cheaper means of transporting bulky commodities, this undermines the competitiveness of smallholder producers. Along with the low yields and limited volume of production that also limit competitiveness, an overwhelming proportion of the national surplus is traded in domestic markets. In an effort to promote market-led agricultural development, Ethiopia has recently formulated an ambitious agricultural and input marketing strategy that aims to address each of these limitations in the marketing system (MoARD, 2005). In the long-term, Ethiopia's competitiveness in chickpea exports would critically depend on improving productivity, grain quality and ability to consistently supply required volumes of market-preferred commodities at competitive prices and at the right time.

The study has shown that existing marketing systems in the country do not always value quality properly, especially at the lower end of the value chain. This makes it difficult for farmers to appreciate and internalize quality issues, as prices may not always reward good behavior in maintaining quality. There is a need for a more efficient marketing system that helps reduce transaction costs and create incentives for smallholder producers to adopt new technology for improving productivity and enhancing quality and reliability of supply. The complex and extended nature of value chains in chickpea markets along with pervasive asymmetric information prevents attainment of efficiency and may even crowd out reliable suppliers of high quality produce at reasonable prices.

Addressing these concerns is paramount in harnessing the unexploited growth opportunities that lie in the chickpea sub-sector. While improving viable and efficient market linkages is important for both domestic and export markets, there is a lack of knowledge and transparency in seasonal price patterns, price-quality relationships and seasonal market demand in alternative export markets. Lack of such reliable information has often led to extreme speculation and unwarranted pricing patterns and volatility in chickpea markets. Unfounded expectations on the side of producers and traders have led to breakdown of trust and relationship. The study has also found that inadequate horizontal and vertical linkages among chickpea market participants, limited participation in value addition and processing and limited access to information, credit and related business services continue to stifle the marketing system, making it vulnerable to manipulation by few rent-seeking intermediaries and actors.

Partners:

EIAR  
ILRI  
IPMS/CIDA  
EIAR  
MoARD (Ethiopia)

Publications:

**Shiferaw B, Jones R, Silim S, Hailemariam T and Gwata E.** 2007. Analyses of production costs, market opportunities and competitiveness of Desi and Kabuli chickpeas in Ethiopia. IPMS Working Paper 3, ILRI, PO Box 39063, Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics.

**Shiferaw B and Hailemariam T.** Forthcoming. Structure and functioning of chickpea markets in Ethiopia: Evidence based on analyses of value chains linking smallholders and markets. IPMS Working Paper, ILRI, PO Box 39063, Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics.

***1.C.2 Pigeonpea sub-sector study in Kenya (ESA)***

Rationale: Pigeonpea production in Kenya has been steadily increasing in the past decade. Comparison of trends during the period 1996–2005 showed a 183% increase in production, 28% increase in area under the crop and a 54% improvement in yield. The increase in production, acreage and yield may be attributed to use of improved technologies. However, poor access to seeds and susceptibility of some pigeonpea varieties to field pests are the major constraints to utilization of improved varieties. Despite these constraints, pigeonpea competes favorably with other legumes grown in the dry areas (eg, beans, green gram and cowpea). This study uses a value chain analysis approach to identify the opportunities and challenges that prevail at different stages in the pigeonpea subsector in Kenya spanning a full range of economic activities ranging from provision of inputs and services to production, value addition and product development, marketing and consumption. This approach overcomes the limitations of traditional static subsector analyses and focuses on economic interlinkages and interdependencies that affect the systemic competitiveness of the pigeonpea economy. This approach is considered to provide new insights and better understanding of the policy-relevant issues that matter for improving productivity and competitiveness of pigeonpea in the new globalized markets.



Project objectives: To avail empirical data needed to facilitate formulation of strategies to strengthen pigeonpea value chains and to increase competitiveness and participation of producers in high value markets, especially export.

Project outputs:

- Pigeonpea production and marketing constraints and opportunities analyzed
- Main pigeonpea marketing agents and channels identified
- Recommendations on how to enhance pigeonpea commercialization in Kenya

Methods: Value chain analysis approach was used to identify the opportunities and challenges that prevail at different stages in the pigeonpea subsector in Kenya spanning a full range of economic activities ranging from provision of inputs and services to production, value addition and product development, marketing and consumption. The study entailed review of literature together with collation and analysis of secondary data. Secondary data was augmented with collection and analysis of two primary data sets: farm-level production and post farm-level marketing data. The farm-level data comprised of production data from 400 randomly sampled households from Mbeere and Makueni districts first in the year 2003 and then 2005. The post farm-level data included information from a rapid market survey conducted on 44 marketing intermediaries in Machakos district and in the city of Nairobi in the year 2006.

Milestones:

- Household and market level data collection successfully completed
- Data analysis finalized
- Research report completed and ready for publication

Major findings: About 60% of pigeonpea growers in Kenya take their produce to pigeonpea markets, selling about two-thirds of their total production. The crop is marketed either as dry grain, processed (split) dry grain (dhal) or green (vegetable) pigeonpea. Most market participating farmers sell at the farm-gate. Dry grain is marketed through six marketing channels: rural open-air retail markets, rural retail shops, urban open-air retail markets, urban retail shops, urban supermarkets, and the export market. Dhal on the other hand is marketed through three channels namely, urban retail shops, urban supermarkets, and export. Lastly, vegetable pigeonpea is also marketed through three main channels, ie, rural open-air retail markets, urban open-air retail markets, and export. These channels involve myriad players and hence tend to have high marketing costs.

Recent studies show that there are good domestic, regional and export trade opportunities for pigeonpea. However, the domestic market for dry pigeonpea is thin and volatile. Regional trade serves to smoothen the variability in local production. Unlike other legumes that are mainly traded locally, pigeonpea can be exported to India and other overseas markets including the USA, Canada, Europe, the Middle East and South Africa. The Indian market has been attractive to East African exporters because of its large size in terms of volumes demanded, low expectations on product quality, and low import duty. On the other hand, export to other markets is driven by the higher and relatively stable prices compared to the traditional Indian export market. Kenya's export of frozen fresh peas to high-value European markets has great potential for expansion in the pigeonpea subsector. Nonetheless, it is constrained by inconsistent supply, limited investments in post harvest handling and packaging to ensure strict quality standards, and insufficient market research to identify consumer preferences in the niche markets.

For the pigeonpea subsector to become competitive and expand, productivity will need to be increased, production timed, marketing costs reduced, and quality standards established and strictly complied with. Introducing simple, easily administered quality standards that are based on end-user needs will enable farmers, traders, and exporters to exploit quality-conscious niche markets in Europe and North America. Expansion of domestic production will also require targeting international markets, particularly India, where demand is growing. However, these markets are highly competitive and require careful timing in terms of planting, harvesting, and marketing. For instance, the Indian market is open to Kenya only during a small window in August/September and closes in October/November when the crop in India is harvested and increased supplies lead to falling prices. Targeting of the Indian market should therefore aim at Kenyan pigeonpea reaching India during the off-season period when import prices are relatively high. This calls for the planting of early-maturing varieties. Furthermore, the high domestic wholesale prices make Kenyan pigeonpea exports less competitive in the international markets. These high domestic prices are fuelled by underdeveloped, fragmented, and extended marketing channels which drive up transaction costs and wholesale prices to processors and exporters.

Therefore, institutional innovations that link producers more directly with exporters and processors or shorten the extended supply chain are needed in order to reduce transaction costs. Such innovation includes formation of farmer organizations which can facilitate farmers' access to improved technologies and create opportunities for forward contracting. Contracting offers exporters and processors access to larger and reliable supplies.

The future policy framework should target: (1) strengthening efforts for upscaling available varieties, (2) reviewing variety testing and approval systems to reduce delays in accessing new germplasm, (3) understanding existing informal seed supply systems and their importance as a source of low-cost but good quality seed to resource-poor farmers, (4) developing systems that allow for marketing of affordable certified seeds, and (5) promoting of contract farming and group marketing strategies to ensure consistent supply and strengthen market power of small producers.

Partners:

- ICRISAT
- TechnoServe
- FAO
- USDA
- CAPRI

Publication:

**Shiferaw B, Okello J, Muricho G, Jones R, Silim S and Omiti J.** In press. Unlocking the potential of high value legumes in the semi-arid regions: Analyses of the pigeonpea value chains in Kenya. Socioeconomics and policy research report. PO Box 39063, Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics.

***1.C.3 Using markets to promote the sustainable utilization of crop genetic resources – case of pigeonpea in Makueni district, Eastern Kenya (ESA)***

Funded by: ESA division, FAO, Rome and Sustainable Commercialization of Seeds in Africa (SCOSA) and IFPRI

Project rationale: Kenya was selected for one of the case study countries under the overall project on “Using Markets to promote the sustainable utilization of crop genetic resources” because improving access to seeds and varieties and maintaining local diversity are important issues in the current agricultural development and biodiversity strategies of the country. The research results will provide the necessary evidence to overcome serious deficiencies in existing seed policies that work against the best interest of marginalized small-scale farmers in semi-arid areas of Kenya. Our choice of study area (Makueni district, Eastern Province) and the crop (pigeonpea) was made because existing seed policies have led to a shift away from well-adapted dryland crops with significant levels of local diversity, resulting in increased levels of food insecurity as well as reduction in on-farm genetic diversity conservation. This situation is likely to become more acute as global climate change leads to increased climatic variability, and one of the few immediate options available to small-scale farmers is to use the local crops and varieties that are better adapted to such environments. The project will result in an increase in the awareness of key decision-makers of the impacts of seed sector regulation and emergency seed relief approaches on the functions of agricultural and seed markets and the access farmers have to seeds and a diverse supply of crop genetic resources. The project will also provide tools to improve the design and implementation of such policies in a collaborative effort with the decision-makers themselves.

Main objectives:

- How does emergency seed relief and the proposed Kenyan seed sector regulation reform, affect farmer access to crop genetic resources in local markets?
- How do we measure farmer access to crop genetic resources, especially in relation to crop genetic diversity, in local markets?
- How does access to CGR in markets affect farmer welfare and on-farm crop biodiversity?
- How can the design or implementation of emergency seed relief and seed sector regulation in Kenya be changed to improve the access farmers have to seeds and varieties in markets and promote the sustainable utilization of crop genetic resources?

Milestones and achievements: For the purpose of the project, detailed farm and market levels surveys among pigeonpea growers and traders were conducted in Makueni district of eastern Kenya. The market surveys were

conducted to elicit information regarding various stakeholders (160 traders in total) in the seed and grain value chain in 8 major market-sheds in the Makeni district. This was followed by detailed, farm-household surveys conducted in 4 major pigeonpea growing divisions, covering 400 farmers during August-September, 2007. A detailed agro-morphometric characterization (over 250 seed samples) work was also carried out in two field locations (Kibhaco and KDM) from the seed samples collected at the farm-household and market levels to understand the diversity levels provided by farm and markets for pigeonpea in the study region.

The quantitative analyses on the data collected from markets and farm-households to determine the impact of market participation on farm level diversity as well as the impact of various seed interventions on farm production as well as farmer welfare is underway. The results will be submitted in a final report form to both FAO and ICRISAT during May 2008.

**Major findings:** Over the last two decades, several seed-related programs have been initiated in eastern Kenya to improve farmers' access to quality seeds of dryland cereals and legumes. They are provided during two occasions, regular and emergency times. But very often, the formal supply mechanisms either marginalize or limit their role in provision of seeds other than maize. In the absence of any formalized systems of seed provision for other dryland crops, such as sorghum and pigeonpea, local markets play and its actors play a key role in meeting the seed-needs of the farmers during normal and distress times. Among the seed distribution mechanisms in eastern Kenya, farmers experienced a significant impact of ICRISAT promoted producer marketing groups (PMGs) towards increased access to improved and quality planting materials of pigeonpea during normal and distress periods, compared to community based seed production or seed fairs. The seed prices were more stable in the PMG sites than in the other intervention sites, due to proper marketing tie-ups for seeds and the grain. However, there still exists a need for more effective and sustainable, seed based initiatives to provide quality seeds on time as well as in improving the cultivar diversity of dryland cereals and legumes during normal and distress periods in the semi-arid regions of eastern Kenya.

**Partners:**

IFPRI  
FAO

**Publications:**

**Nagarajan L, Audi P, Jones R and Smale M.** Forthcoming. Seed provision and dryland crops in the semi-arid regions of Eastern Kenya. Discussion paper submitted, reviewed and accepted for publication at IFPRI.

**Audi P, Nagarajan L and Jones R.** Under review. Seed interventions and cultivar diversity pigeonpea: a farmer based assessment in Eastern Kenya. Paper submitted and under review by Journal of New Seeds.

***1.C 4. Agricultural subsidies in Southern Africa: A summary of current debate and evidence (ESA)***

**Project Rationale:** Poverty and food insecurity challenges are high on the agenda of many African governments. Political pressure to get agriculture moving-- increase agricultural productivity, food security and incomes are at the centre stage. Accelerating agricultural growth remains a necessity for meeting the Millennium Development Goal (MDG) of cutting hunger and extreme poverty in half by 2015. As part of a response to some of these challenges, the New Partnership for Africa's Development (NEPAD), African Union and the International Center for Soil fertility and Agricultural Development (IFDC) organized the Africa Fertilizer Summit in June 2006 to discuss the future role of fertilizer in stimulating sustainable pro-poor productivity growth in agriculture. As approaches and strategies for increasing agricultural productivity are being debated, it is imperative that the right instruments are used and at the right time and in the right circumstances and not just quick fixes that are unsustainable.

**Methodology Used:** This study aimed at contributing towards a regional policy debate in the context of the Program on Strategic Analysis Knowledge Support System (SAKSS) for the southern African countries. It focused essentially on the review of literature of recent agricultural inputs –particularly in Malawi, Kenya, Mozambique and Zambia. Key areas referred to include the principles and definitions of subsidies, objectives, problems of implementation –particularly the targeting and efficiency problem as well as who has to pay for the subsidies.

**Major Findings:** Agricultural subsidies are generally popular in many African countries. Governments adopt subsidy programs as a way of supporting agricultural and economic growth. The most common are input

subsidies— these are commonly targeted at poor farmers. Such programs are mainly associated with fertilizers, seeds and crop protection products. Typically, inputs are given to farmers for free, or at very low prices so as to promote input use and productivity growth. Output subsidies are mainly associated with price support for strategic crops. Output price supports by government to farmers are seen as a means of creating incentives for domestic farmers to produce certain crops (Minde and Ndlovu, 2007). Subsidy programs commonly pursue specific objectives that justify the necessity and appropriateness of these programs. Typically the typology of objectives of subsidies and their description across countries ranged as follows:

|                         |                                                                                                 |
|-------------------------|-------------------------------------------------------------------------------------------------|
| Financial objective     | - Increase the net income of farmers, traders, or other participants in the agricultural sector |
| Environmental objective | - Restoring soil fertility-fertilizer subsidy program                                           |
| Social objective        | - Improve welfare, improving incomes, poverty alleviation                                       |
| Economic objective      | - Correct missing or imperfect markets, increase real income for the economy or society overall |
| Political objective     | - Building political support or ensuring political stability                                    |

Options for subsidies and recent experiences in southern Africa ranged from targeted government input distribution, collective action approach, starter pack and targeted inputs programs such as the one for Malawi.

It was also found out that subsidies have both advantages and disadvantages as far as financial, economic and environmental issues are concerned. Some of the advantages are--increased agricultural output and/or incomes, offsetting policy induced market distortions, encourage technology adoption by farmers eg, more use of fertilizer at optimal levels and restoration of soil fertility; social protection and environmental protection. The disadvantages were financial burden to governments, inefficient use of inputs and problems in targeting of beneficiaries.

If subsidies have to be provided, then they have to be smart—which implies specificity, measurability, achievability of purpose, result oriented and timely delivery of products. The literature also points out that smart subsidies should:

- promote the factor or product as part of a wider strategy
- favor market based solutions
- promote competition
- pay attention to demand
- promote economic efficiency
- empower farmers
- devise an exit strategy
- pursue regional integration
- ensure sustainability
- promote pro poor growth

The above are useful criteria that should be seriously heeded by policy makers before pressing the button for the subsidy train. An ex-ante evaluation of alternative pathways with some weights for the 10 points, which could be based on the objectives—would be useful.

The Africa Fertilizer Policy Toolkit by Morris et al. (2007), provides a guide to policy analysts and program designers on appropriate fertilizer subsidy program implementation by enquiring on the objectives of the fertilizer program and types of farmers to be targeted, whether or not a fertilizer subsidy program is the best option for meeting objectives and target group needs, and what are the binding constraints and potential solutions.

The following recommendations emerged from this study:

- Subsidies should be generally well targeted, market friendly, financially sustainable and time bound.
- Subsidies should go for an integrated approach that addresses structural problems affecting input demand and supply, as part of strategies to promote input use.
- Appropriate policy prescription on subsidy programs requires a comprehensive social cost benefit analysis. This should take into consideration country specific socio-economic, financial, political, agro-ecological and environmental conditions.

Publication:

**Minde IJ** and **Ndlovu PJ**. 2007. Agricultural subsidies in Southern Africa: A summary of current debate and evidence. Regional Strategic Analysis and Knowledge Support System for Southern Africa (ReSAKSS-SA). Draft policy brief. Pretoria: South Africa.

***1.C.4 Enhancing fertilizer access and utilization in Limpopo province through small packs (ESA)***

Background: Smallholder area of Limpopo Province is vulnerable to frequent drought with poor soils and declining productivity. Drought and low soil fertility are two problems that commonly keep smallholder farmers in a cycle of poverty. Yields will not increase unless farmers apply fertilizer to replace lost nutrients. However, fertilizer use remains very low because of costs, availability and high risk due to uncertain rainfall. Appropriate use of fertilizer can help increase yields; however, few smallholder farmers apply this.

Following the partnership between—the private sector (SASOL Nitro and Progress Milling) and public sector (Limpopo Department of Agriculture—LPDA and ICRISAT) in Limpopo Province, a project was put in place to establish whether farmers could sustainably increase the use of fertilizer if more affordable packages were made available to them. For three seasons—2004/05 to 2006/07 SASOL Nitro, Progress Milling, LPDA and ICRISAT joined hands to supply different packs of fertilizers—especially ammonium nitrate to farmers in the Limpopo Province. ICRISAT had a role of facilitating the monitoring and evaluation of the project. The study was aimed at assessing the factors affecting uptake of small packs of fertilizer.

Objectives:

The specific objectives of the study were to:

- Characterize buyers and non- buyers of fertilizer
- Determine the factors which affect pack size preference
- Inform policy on strategies that could be pursued as a way of increasing fertilizer use to improve smallholder crop productivity

Methodology: A total of 179 farmers were interviewed in the Limpopo Province with the view to understand how they managed their soil fertility status. Almost two thirds of these farmers used chemical fertilizers and were classified as buyers whereas the non-buyers did not use fertilizer. The survey was conducted in three districts namely Mopani, Capricorn and Vhembe. The interest on the non- buyers was to investigate why these farmers would prefer not to use fertilizer given equal opportunities with the buyers. An investigation on what drove the buyers to buy the pack sizes they bought was carried out to determine the market of small pack fertilizer.

Preliminary Findings: Buyers of fertilizer were not different from the non- buyers in terms of age, farming experience and household size. Resource endowments like cattle ownership and subsequent use of cattle manure on maize cannot be used to explain differences between buyers and non-buyers. Cattle ownership is actually high among non- buyers but the subsequent quantities of cattle manure used on maize are lower among non-buyers.

Buyers of fertilizer were driven by their bigger fields and a higher level of annual income compared to non-buyers. However, the extra income for buyers could be coming from crop sales since the most common source of income for smallholder farmers in Limpopo province is the welfare support from government in terms of pension for the old age, disability grants and child support for children below 14 years.

Farmers with a higher education level were amongst the buyers and these farmers also attended more extension meetings than non- buyers. Cereal production of buyers was significantly higher than that of non- buyers in any given season because of the effect of fertilizer on yield.

The traditional 50kg bags dominated the sales with almost 90% of the sample buying both basal and top dressing fertilizer. The farmers who bought the small packs have less than five years of using fertilizer, it is their first time or they are in their second year of using fertilizer. All the small packs were bought from the local depots and no transport cost was paid. In terms of the cost of fertilizer, the price per kg was not different, which meant that in order to buy 50kg pack, a farmer would need five times the amount of money required to buy a ten kg pack. The total investment required would become too high for a poor farmer making the fertilizer unaffordable. Farmers who had stopped using fertilizer cited the affordability as a major drawback and the

coming of small packs would provide a financial relief. All farmers who bought small packs used spot application to apply fertilizer and this could be attributed to the teachings of extension.

Small packs therefore provide an essential starting point for using chemical fertilizers. If there is a timely and consistent supply for small packs at local depots, the demand would increase because it captures those who have given up on fertilizer, the non-buyers who want to try, those who cannot afford large packs and those with small fields or backyard vegetable gardens.

**Milestones:** The study managed to establish the significance and role of small packs of fertilizer with possible implication on the advantages of divisibility for other related technologies. Sustainability of supply of small packs is contingent on there being sufficient demand to convince industry to continue supplying them. This is critical because diversion from the traditional 50 kg to smaller pack sizes implies an additional cost.

**Publications:**

**Minde IJ, Mazvimavi K, Pedzisa T, Ndlovu P and Musitini T.** Forthcoming. Small packs fertilizer use in Zimbabwe and South Africa.

**Minde IJ, Pedzisa T and Dimes J.** 2007. Enhancing fertilizer access and utilization by smallholder farmers in Limpopo Province through small packs. Draft Report.

***1.C..5. Dry season feeding of livestock in the SAT of Zimbabwe: market led technology development (ESA)***

**Project rationale:** This project aims at improving incomes and livelihoods in the SAT of Zimbabwe by increasing livestock productivity and marketing of small-scale livestock keepers. The project identifies and evaluates alternative product market systems as drivers for farmers' adoption of improved management technologies and the development of more effective input supply systems. It assesses the form and speed of the transition towards more intensive feed utilization in southern Africa and identifies feed options offering the prospect of enhancing crop-livestock system productivity.

**Methodology:** Data collection was done in three phases and integrates qualitative and quantitative information. A reconnaissance survey engaged the various stakeholders along the value chain (September–October 2005); an in-depth household survey in six districts involved 825 households (April–May 2006); feedback and verification sessions were held with the communities (May 2007) and at a multi-stakeholder workshop at national level (October 2007).

**Milestones:**

- Baseline analysis of livestock production and marketing in semi-arid livestock systems in Zimbabwe
- Identification of dry season feed/fodder options used in semi-arid Zimbabwe - taking account of those currently used, and those available from research or the market
- Identification and conceptualization of livestock market opportunities and value chains in southern Africa and how this may stimulate the demand for livestock, improve production and inputs, especially improved feed system, to contribute to income growth
- Contributions to the establishment of new livestock networks
- Goat Forum, association that promotes goats for better livelihoods, Bulawayo.
- Government/FAO/NGO Livestock Technical Consultative Group, Harare.

**Major findings:**

*Comparative advantage of goats for small-scale farmers*

Goats are largely neglected although most small-scale farmers keep them. Unless better markets for goats are developed farmers do not derive the appropriate benefits from their animals. Goats fulfill different user functions than cattle particularly for resource-poor farmers' livelihoods in mixed crop-livestock systems. Farmers use cattle primarily for flow products, such as draft power and milk, and supporting subsistence farming. Although cash is important, they may be reluctant to sell their cattle, whereas goats are primarily kept for immediate cash needs and meat, adding income and insurance. Cash from both cattle and goats is primarily spent on food and education, followed by human health and farming inputs. Poor households depend more on cash from goats, especially as about 40% do not have cattle. Keeping and disposing goats is less risky (reproduce faster, more drought resilient). Goats are therefore critically important for food security, directly through meat and milk, and indirectly through cash. Many women own goats and actively participate in

decision-making. Therefore, targeting goat production can contribute to risk mitigation, improved nutrition, income growth and empowerment of vulnerable groups (poor, women, HIV/Aids).

#### *Goat sales by poor and better off households*

As expected, farmers with larger flocks sold more goats; on average, farmers sold between two and seven goats with significant differences across the study's six districts. The more telling figure, however, is the proportion of the flock sold/exchanged. Households with more than 20 goats sold only 13% of their flock, and often have alternative means to cover household expenses. With the lower offtake rate, these households are most probably able to maintain, or even increase, their flock sizes. However, farmers with small flocks sell as much as 36% of their animals each year, creating a poverty trap as they are unable to rebuild their flock sizes. Functional markets will benefit both the better off and the poor. Poorer households tend to sell only one or two animals a year but do so only in grave need and a functional market will guarantee better prices. Better off households with more animals to sell will also benefit from the higher prices.

The study results further show that market participation was higher in districts with better markets such as Binga, Gwanda and Beitbridge. Also, within districts farmers in wards with better market access sold more animals than those with poorer market access.

The study tried to assess whether those farmers that sold more animals in turn invested more in management strategies. Farmers show a tendency to increase managerial inputs that directly benefit commercialization, such as castrating young males, culling unproductive animals and some aspects of disease control. However, these relationships are not as strong as they should be; a business-oriented mindset is not yet developed. Generally, investment patterns are weak; farmers lack information, input and incentives to increase production. On the other hand, the data illustrate a level of preparedness to invest, which can be used as a starting point for future interventions.

#### *Livestock markets and services*

Traders dominate the market in districts where markets are better developed, such as Binga, Gwanda and Beitbridge and goat numbers support the development of the enterprise. Together they buy 43% of all goats available for sale. Of equal importance is the 40% of goats bought by farmers, particularly in areas where markets are least developed. This indicates a very high rate of flux between farmers who buy goats for home consumption, flock building activities or resale. Although local consumers contribute only a small fraction of total purchases, their presence as buyers provides alternative marketing routes for farmers and allow for increased local competition.

The lack of formal goat sale facilities in Zimbabwe is a great barrier to the development of a competitive and sustainable goat enterprise. Goats are often sold alongside formal cattle sale pens and at collection points, but there is no infrastructure to keep goats and display and sell animals in an orderly manner. Goats suffer without feed and water prior to sale and slaughtering, increasing stress and affecting animal condition. High transport costs also inhibit the development of the sector; goats are transported in conventional trucks without multiple tiers that would make transport more cost effective.

Much can be done to facilitate market development - establishing appropriate market information systems such as the dissemination of price structures, grades and standards will improve farmer's decision making powers and open up markets. Thirty-one percent of farmers had no access to formal information on goat marketing, the rest relied on other farmers, livestock traders and local authorities - governmental support services were considered as poor sources of market information. A functional grading system with simple indicators for determining quality standards as well as transparency in price setting need to be established to foster confidence in goat markets.

#### Publications:

**Homann S, Van Rooyen A, Moyo T and Nengomasha Z.** 2007. Goat production and marketing: Baseline information for semi-arid Zimbabwe. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics. Pp77.

**Homann S and Van Rooyen A.** 2007. Briefing notes. Goats in semi-arid Zimbabwe: The importance and the development challenge. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

**Homann S and Van Rooyen A.** 2007. Briefing notes. Improving goat production in semi-arid Zimbabwe: animal health and dry season feeding. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

**Van Rooyen A and Homann S.** 2007. Briefing notes. Matabeleland's informal goat markets: Their role and function in smallholder livestock development. PO Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

**Homann S and Van Rooyen A.** 2007. Unexploited agricultural growth: the case of crop–livestock production systems in Zimbabwe. Paper presented at 2nd conference of African Association of Agricultural Economics (AAAE), 2007, Accra, Ghana.

**Nyati N and Homann S.** 2007. ZITF proves value of goats. New Farmer Magazine. Herald, Box 396, Harare, Zimbabwe.

**Homann S.** 2007. Gain from goats. SATrends no. 74. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Output 1D. Forecasting models, market linkage models and analytical tools developed and promulgated in collaboration with other CG centers and partners for situational analysis and outlook in commodities & livestock including phyto-sanitary standards (SPS) and technical specifications for international trade and new knowledge shared with partners**

***1.D.1 Prices: Situation and outlook (Asia)***

Project rationale: This study is aimed at providing a bird's eye view of the trends in the global prices of the agricultural commodities. Specifically, it examines the price trends for cereals, pulses and oilseeds as a background for a more detailed analysis of the price trends of the ICRISAT mandate crops. It is aimed to increase the awareness of the historical trends in prices and future prospects and its implications for policy and research.

Preliminary/ major finding: The real prices for agricultural commodities at the global level have declined by about 2% between 1970-2005. Of the broad commodity categories, pulses have experienced the sharpest decline in prices, with export prices declining by 4.6%; followed by oilseeds by 3.8% and cereals by 1.9%. The general pattern that the prices have followed is an increase in the seventies, followed by a decline in the eighties and the nineties, and a gradual recovery in the years 2000-05.

*Mandate crops:* Price trends for the ICRISAT mandate crops have shown similar trends.

*Sorghum and millets:* The price of sorghum decreased by 3.6 % per annum over the years 1970-2000 but increased by 2.1% per annum between 2000-05. While a majority of the cereals traded are used for human consumption, sorghum is largely traded to fulfill the demand from the feedstock sector. Between 2003-05 about 9-10% of sorghum is traded relative to its production compared to 15-20% in the eighties. However, the price difference between sorghum and maize is narrowing in recent years, an indication of growing demand for sorghum. The price of millets increased by 2.6% in the period 1970-2005 and 7.1% in 2000-05. The volumes of millets that are traded are negligible compared to the total production quantity; averaging less than 1% implying most of it is consumed domestically.

*Chickpeas and pigeonpeas:* Chickpeas assume a dominant position in the world trade for pulses accounting for nearly 13% of the total pulse trade, in terms of quantity. The demand for pulses derives from both the food and livestock feed sector. Exports of chickpeas have increased impressively with exports growing by nearly 7% between 1970 and 2005. This is also reflected in the share of chickpea exports to its production that grew from around 2% in the seventies to about 10% in 2003-05. Chickpea prices decreased by 3.5% in 1970-2005 and increased by 1.1% in 2000-05.

The price trend for pigeonpea prices is marked by a high degree of volatility as the major pigeonpea growing regions are in North Africa, India, Malawi and Myanmar, all of whose agriculture is extremely vulnerable to weather fluctuations. Consequently, the quantities that are traded vary considerably, exacerbating the volatility in the prices.



*Groundnut:* The real export prices of shelled groundnut and groundnut oil have declined over the period 1970-2005 at roughly the same rate, at 2.6% and 2.8% respectively. For groundnut oil, while production increased by more than 2% between 1970-2005 export quantities declined by 2.5%, implying that an increasing portion of the groundnut oil is being consumed domestically and not being traded. In the recent years there has been a decrease in the share of shelled groundnut exported to its own production from 5.2% to 2.3%, and from 13.3% to 3.8% for groundnut oil. Thus despite the growing demand for edible oil and protein meals, the import demand for groundnut has been declining during the last several years, perhaps due to growing stringent quality specifications against aflatoxin contamination.

*Outlook:* The years 2006-07 have seen a further increase across the board in the prices of all the agricultural commodities. While supply shortages and low worldwide stocks due to consecutive bad harvests in major producing countries account for some part of the spike in prices, the increasing trend is expected to be sustained over the next decade due to more systemic changes in the demand structure. Asia, Latin America and Africa are now seen as markets that will drive trade growth. The broad based income growth in these countries, which coupled with a continued increase in population, is touted as the reason. Additionally, the increased demand from the bio-fuel industry has affected all the agricultural commodity prices and is expected to continue to do so in the medium term.

Partners:

ICRISAT : P Parthasarathy Rao, MCS Bantilan and B Shraavya  
University of Newcastle : Frank Agbola  
IFPRI : Siwa Msangi

Publications:

**Parthasarathy Rao P, Agbola F, Bhagavatula S and Bantilan MCS.** Forthcoming. Global price trends for ICRISAT mandate crops: Situation and outlook. Draft report. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Parthasarathy Rao P, Agbola F, Bhagavatula S and Bantilan MCS.** Forthcoming. Global price trends for ICRISAT mandate crops: Situation and outlook GT-IMPI Policy brief no 12, Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

### ***1.D 2. Agricultural commodity prices looking up***

The real prices for agricultural commodities at the global level have declined by about 2% between 1970-2005. Of the broad commodity categories, pulses have experienced the sharpest decline in prices, with export prices declining by 4.6%; followed by oilseeds by 3.8% and cereals by 1.9%. The general pattern that the prices have followed is an increase in the Seventies, followed by a decline in the eighties and the nineties, and a gradual recovery in the years 2000-05.

Price trends for the ICRISAT mandate crops have shown similar trends. For example, the price of sorghum decreased by 3.6 % per annum over the years 1970-2005 but increased by 2.05% per annum between 2000-05; millets by 2.57% and 7.08%; chickpeas by 3.45% and 1.1%; groundnuts (shelled) by 2.64% and 1.2% respectively. As much as 75% of the global production of the ICRISAT mandate crops come from developing countries. Interestingly developing countries are also the main sources of import demand for chickpea and pigeonpea, while for groundnuts, developed countries account for bulk of imports.

Among the ICRISAT mandate crops sorghum is the most traded crop by volume with 5.4 million tons (8.9% of its production) being exported in 2005 and millets formed the least with less than 0.4 million tons (1.1% of its own production) being exported. Much of the global trade in sorghum and millets is for feed use and the increased demand for dairy and meat products, and availability of substitutes like maize would be the main drivers of their prices. The price difference between sorghum and maize is narrowing in recent years an indication of growing demand for sorghum. Sorghum and maize prices registered an increase in 2006 after a small dip in 2005.

Chickpea and pigeonpea imports to India, the main importer, have been a major determinant of the world prices of these commodities. For groundnut, despite the growing demand for edible oil and protein meals, the import

demand has been declining during the last several years, perhaps due to growing stringent quality specifications against aflatoxin contamination.

The years 2006-07 have seen a further increase across the board in the prices of all the agricultural commodities. While supply shortages and low worldwide stocks due to consecutive bad harvests in major producing countries account for some part of the spike in prices, the increasing trend is expected to be sustained over the next decade due to more systemic changes in the demand structure due to income and urban population growth in the emerging markets of Asia, Latin America and Africa. Additionally, the increased demand from the bio-fuel industry has increased all the agricultural commodity prices and is expected to continue to do so in the medium term.

Publication:

**Parthasarthy Rao P and Bantilan MCS.** 2007. Agricultural commodity prices looking up. SATrends no.85. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

*1.D.3. Establishing input output linkages (Asia)*

Project rationale: ICRISAT along with the participation of the local partners is implementing a project on “Enhanced utilization of Sorghum & Pearl millet grains in the Poultry feed industry to improve livelihoods of small-scale farmers in Asia” funded by the CFC in the India, China & Thailand. A new concept of backward and forward linkages involving the bulk marketing of grain through Farmers’ Associations was evolved & implemented through the project. To facilitate the production and marketing of the produce, it became crucial to establish direct linkage between the farmers, input suppliers, credit agencies and the grain processors such as the poultry feed manufacturers. Here we highlight the credit linkages carried out in the project clusters in 2007.

Traditionally, the farmers have been borrowing from the local credit institutions & individuals for the fulfillment of their credit needs. The borrowings from individuals are at exorbitant interest rates. The credit lent by local co-operative societies is for a group of farmers & not individual farmers. In this case, the availability of credit depends on the performance of the group & not the individual farmer’s repayment performance.

Approach and methodology: From the experience in the first year it was thought that in the second year a top-down approach would be best where we first talk to the top level departmental heads of various nationalized banks, State Bank of India for Andhra Pradesh, and for Maharashtra, the State Bank of Hyderabad. The focus would be on loans against their stored produce in the warehouses and issue Kisan Credit Cards with a credit limit of Rs. 50,000 to the eligible farmers. A series of successful meetings were organized between the farmers associations and the bankers.

Preliminary/major findings: The inclusion of farmers in the meetings was a very good step as they got exposed to the requirements of the various kinds of services available with the bank & a sense of fulfillment of the obligations has developed within them. This would go in a long way in mutual benefit of the relation between the bank & farmers.

The requirements of the bank for providing produce-marketing loans based on warehouse receipts were clarified & obligations of the owner & maintainer of the warehouse along with the recipient of loan were clearly known. Credit linkage has to be associated with output linkage as the bank has a condition by which stocks can be released only after repaying the loan. There is a need to evaluate how these activates would be translated at ground level and what the obligations of different stakeholders would be.

105 farmers in the Andhra Pradesh clusters have been issued crop loans. Another 500 farmers are in the process of getting linked to the banks, SBI in Andhra Pradesh & SBH in Maharashtra. Most farmers earlier had some knowledge of the loan facilities but very few had actually availed the benefits of these loans. Extensive meetings with the farmers and explaining the exact process by which they can secure loans have resulted in extending the reach of this linkage. Success of availing produce marketing loans would be crucial in establishing long-term contacts with the bankers for future developments such as KCC.

Partners:

Andhra Pradesh : FFA, SVVU, Janaki Feeds Private Limited

Maharashtra : MAU, KVK- Beed, VHL

Karnataka : UAS- Dharwad, NGO

China : SRI-LAAS  
Thailand : FCRI/FCRC

Publications:

**Gurava Reddy K, Parthasarathy Rao P, Reddy BVS, Reddy AR, Rao CLN, Chengal Reddy P and Janardhan Rao Ch.** 2007. Enhancing technology generation and transfer through coalition approach: A case of sorghum poultry coalition, Andhra Pradesh, India. *International Journal of Technology Management and Sustainable Development*: 5(2). Bristol, UK.

**Birthal PS and Parthasarathy Rao P.** 2007. Changing agricultural scenario: Institutional innovations for linking small farmers to markets. Paper presented at the National Seminar on Agrarian Distress: Causes and Remedies, August 1-2 2007, National Center for Agricultural Economics and Policy Research, New Delhi. NCAP and Indian Society of Agricultural Economics.

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**Alur AS, Ravinder Reddy Ch, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Markets access for poverty reduction and improved livelihoods of small and marginal scale dry land farmers: Presented at the International Conference on Ethnographic Discourse of the Other. University of Hyderabad, 3-5, July 2007, Hyderabad, India

**Ravinder Reddy Ch, Alur AS, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Building social capital for improving the livelihoods of small and marginal farmers in SAT regions of Asia. Presented at the International Conference on Ethnographic Discourse of the Other. University of Hyderabad, 3-5, July 2007, Hyderabad, India

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**CFC/FAO/ICRISAT.** 2007. Brief Report on credit linkage activities under CFC-FAO-ICRISAT project, Region 1, India. Project Executive Agency (PEA), CFC / FAO/ ICRISAT project ICRISAT, Patancheru

**CFC/FAO/ICRISAT.** 2007. Brief report on credit and output linkages and models of marketing bulked grains of sorghum and pearl millet in the clusters of Andhra Pradesh and Maharashtra (India) in 2006. Project Executive Agency (PEA), CFC / FAO/ ICRISAT project ICRISAT, Patancheru

**CFC/FAO/ICRISAT.** 2007. Detailed linkage report, region 1, India. Project Executive Agency (PEA), CFC / FAO/ ICRISAT project ICRISAT, Patancheru

***1.D.4. Biofuels: implications for food and feed security (Asia)***

Project rationale: In the face of the rising cost of energy and mounting environmental concerns, bio-fuels, fuels that are derived from renewable sources of plant origin, are increasingly drawing the attention of policy makers in both developed and developing countries as an economically viable alternative to fossil fuels. This has sparked a food vs. fuel debate and is addressed here, and suitable alternatives are explored.

Approach and methodology: The analysis here is based on literature review, field surveys carried out by the ICRISAT team and data from secondary sources such as FAO, USDA, IFPRI and the Government of India.

Preliminary/major findings: The growth in both ethanol and biodiesel production picked up speed since early 2000 and this trend is expected to continue since many governments have now made it mandatory to blend petroleum products with 5 to 10% biofuels

*Bio-ethanol:* Based on the available data from several sources, it is estimated that ethanol production, which was 112.9 million tons in 1991, leapfrogged to 40.3 million tons by 2006. Brazil and the USA are the dominant producers accounting for nearly 70% of global production. China, India, France, Russia and South Africa and

UK are other important producers. The main raw material sources for bioethanol production is sugarcane in Brazil as also other Latin American countries, corn in the United States, corn and wheat in China, sugarcane molasses in India, cassava and sugarcane in Thailand and sugar beet and grains in Europe.

*Biodiesel:* Biodiesel production that accounts for a smaller proportion of liquid biofuels increased from 0.01 million tons in 1991 to 4.0 million tons by 2006. Germany and France are the major producers of biodiesel with USA, Australia and Brazil emerging as new players. For bio-diesel production, the main feed stocks are vegetable oils from rapeseed, soybeans, sunflower oil (in southern Europe) and in recent years, palm oil.

*Food vs. fuel:* There are however, concerns about the future of the biofuels program that lead to diversion of land from food crops and oil crops to energy producing crops. This, it is argued, would lead to food and feed insecurity and also removes crop residues that sustain soil productivity and structure. Researchers at IFPRI have carried out modeling exercises using IMPACTS model that indicate that aggressive biofuel growth would indeed lead to dramatic increase in world prices for 1st Generation feedstock crops, like cassava, maize, oilseeds, sugar beet, and sugarcane. However, other scenarios that allow for crop technology innovation at the farm level and use of cellulosic technology, dampen the effect on food prices considerably. Nevertheless, production of biofuels using cellulosic technologies is still a long way off since we still need to overcome several constraints including production costs.

*India:* Molasses from sugarcane, the main feedstock for bio-ethanol production in India, and consequently, vulnerable to the fluctuating conditions of sugarcane production. Bio-ethanol production capacity in India is estimated is 3.2 billion litres per year, but only 1790 million litres was produced in 2005. Of this only 100 million litres was blended with gasoline as against the policy target of 550 million litres. To meet the targets for 5% blending with ethanol in 2006-07, about 682 million litres of ethanol would be required, while about 1364 million litres would be required to meet the target of 10% blending.

Sweet sorghum, which requires less water than sugarcane and is less costly to produce, is being researched by ICRISAT to be a viable alternative feedstock for bio-ethanol. The use of sweet sorghum will also reduce the food-fuel divide as it is the non-edible stock that is used for the extraction of the fuel-stock. The use of sweet sorghum, which is capable of growing in rainfed lands, is being promulgated in India, China, Thailand, and the Philippines as a part of the BioPower initiative.

The bio-diesel program is still in a nascent stage in India, although the government has ambitious plans to increase bio-diesel production from non-edible oil seeds like *Jatropha* and *Pongamia*. However, *Jatropha* plantations are slow to take off due to the lack of good quality planting material, ownership issues of community or government wastelands and as of now the production capacity is negligible and will take at least another 4-5 years before reliable estimates are available. Demand for biodiesel with similar blending requirements would be 2.62 million tons at 5% and 5.23 million tons at 10% blending.

Partners:

ICRISAT : P Parthasarathy Rao, MCS Bantilan, BVS Reddy  
ABI : KK Sharma

Publications:

**Parthasarathy Rao P** and **Bantilan MCS**. Forthcoming. Emerging biofuel industry: A case for pro-poor agenda with special reference to India. Policy brief no. 13. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Reddy BVS, Ashok Kumar P, Parthasarathy Rao P** and **Sanjana Reddy P**. 2007. Sweet sorghum domains, hybrid sweet sorghum seed, and agronomic practices: an overview. Paper presented at the Global consultation on pro-poor sweet sorghum development for bioethanol production and Introduction to tropical sugar beet agenda, 8-9 November, Rome.

***1.D.5 Regional shifts in chickpea production in India (Asia)***

Project rationale: Chickpea (*Cicer arietinum L.*) ranks first among pulses in India, which is the leading producer accounting for 65% of global production. In terms of growth rates at the all-India level, chickpea area declined by 0.6% per annum between 1965 and 2004, but production increased marginally due to productivity

increases close to 1% during the same period. However, the all-India picture masks the dynamic changes taking place in the centre of production for chickpeas in India.

Approach and methodology: The analysis was carried out using the Government of India database at the all-India state and district level on Chickpea area, production, yield and prices. The trends were analyzed using data from 1965 to 2004.

Preliminary/major findings: During 1965-69 (average), the chickpea area in the northern states of India was about 4.3 million ha, which declined to 1.1 million ha during 2000-04 (average). Similarly, chickpea production fell from 3.1 million t to 1.0 million t. On the contrary, there has been expansion in the area under chickpea in central and southern India - Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Chhattisgarh, and Maharashtra, from 2.2 million ha to 4.2 million ha while production increased from 1.0 to 3.2 million ha. Because of this dramatic change in the centre of chickpea production in 2000-04, the central and southern states of India accounted for 66% of the total chickpea production from 67% of the area compared to 21% of production from 28% area in 1965-69. These trends are reflected in the regional compound growth rates; for the northern and north-eastern states, the growth rates for area and production are significantly negative (< -3%) throughout the 40 year period (1965-2004) and for the central and southern states, area and production growth was significantly positive and the growth rates in production (> +3%) are higher than area growth rates (> +2%).

The disaggregated data further illustrates the dynamic changes taking place in the center of chickpea area and production. The ratio of chickpea area between 1966 and 2004 (area in 2004/area in 1966) shows that chickpea area decreased significantly (ratio<0.85) in 119 districts, while it increased significantly (>1.15) in 69 districts and remained constant (0.85 to 1.15) in only 11 districts. These changes also allude to greater specialization of chickpea area and production. For instance, in 1966 the top 50 districts (in terms of chickpea area) accounted for 63% of chickpea area in India while in 2004 the top 50 districts accounted for 73% of chickpea area indicating greater relative concentration.

The productivity of chickpea has not gone down despite being relegated to marginal and high-risk prone areas with shorter growth cycle due to terminal drought. On the contrary, chickpea productivity increased by 1.7% in the central and peninsular India and is now at par with the yield levels in the traditional growing areas where yields have increased only marginally. This was possible due to development of early maturing chickpea cultivars tolerant to heat stress and with resistance to Fusarium wilt and well adapted to the semi arid conditions leading to higher and stable yield. However, managing *Helicoverpa* pod borer is essential to harvest reasonable yields. Also, chickpea breeding programs need to focus on the most preferred quality traits such as grain size, color, texture, type and cooking quality with a view to satisfy consumer preferences, which vary from region to region.

Partners:

ICRISAT: CLL Gowda, P Parthasarathy Rao and PM Gaur

Publication:

**Gowda CLL, Parthasarathy Rao P, Tripathi S, Gaur PM and Deshmukh RB.** Forthcoming. Regional shift in Chickpea production in India. Book chapter in Milestones of food legumes research. Indian Institute of Pulses Research. Kanpur, India.

***1.D.6. Mixed crop-livestock systems in South Asia: enhancing livestock productivity to benefit the poor (Asia)***

Project rationale: The book on “Increasing livestock productivity in mixed crop-livestock systems in South Asia” addresses the importance of livestock to the poor and makes a case for improving productivity of Crop-Livestock Systems through better targeting of livestock technologies and development initiatives, taking into consideration the close nexus between the crop and livestock sectors and the underlying agro-economic and socio-economic factors driving the system.

Approach and methodology: The book is an update of an earlier study involving the construction of a typology of crop-livestock farming systems for South Asian countries; agro-ecological and socio-economic characterization of the systems identified in the typology; spatial and temporal analysis of crop-livestock systems using GIS; and an understanding of the relative importance of agro-ecological and technological and

socio-economic factors in influencing the type and density of species, adoption of technologies and the productivity of the system.

Preliminary/major findings: For India, a total of 18 Crop-Livestock Systems have been identified. Cattle or buffalo dominate two systems, and are the second or third largest activity in others. Thus, livestock are an important source of livelihood for the rural people. Their share in agricultural income varies from 13% to 41% across systems, and has been growing faster in recent years compared to the crop sector. An important characteristic of mixed farming systems is their domination by smallholders.

Livestock productivity is low, but varies across systems. Differences in productivity are mainly due to variations in feed availability, quality of animals and veterinary infrastructure. Feed availability (dry matter equivalent) ranges between 1 to 4 t/standard livestock units in India. The proportion of high-yielding crossbreds in cattle population oscillates between less than 10% in some systems to over 50% in others. A similar variability has been observed in the adoption of improved poultry. Further, rural poverty is negatively associated with livestock productivity, implying that improving productivity of Crop-Livestock Systems (CLS) would enable smallholders to escape poverty.

Mixed farming is the norm in Nepal, and nine Crop-Livestock Systems have been identified there. Paddy is the dominant agricultural activity and cattle and buffaloes are important species in the irrigated systems spread over the plains ie, Terai region. In the hill-based CLS, coarse cereals/wheat are important crops, and cattle and small ruminants are important livestock species. Livestock contribute about a third of the country's agricultural income. The crop sector has grown faster, implying that achieving foodgrain security is still a major concern. Livestock productivity in Nepal is one of the lowest in South Asia due to a lack of feed and fodder, poor quality of animals and underdeveloped animal breeding/health services, markets and roads. Nevertheless, there are inter-system differences in productivity within the country. It is higher in the systems located in the Terai region having better feed and fodder availability, higher adoption of improved breeds of cattle and buffalo and a better network of veterinary and other infrastructure. Higher income and urban population -- major drivers of demand growth -- are the incentives to invest in productivity-enhancing technologies and practices.

In Sri Lanka, mixed farming is the dominant form of agricultural production. Livestock contributes 14% to agricultural income and about 35% of farm households are associated with livestock production. The clustering of agricultural activities yielded six CLS for Sri Lanka. Livestock, especially cattle, are important throughout the country. Buffalo is also becoming an important milch species in peri-urban dairying. Goat rearing is practiced on a large scale in the low-country CLS. Cattle and buffaloes are largely of the indigenous type in most systems, except in the mid- and up country estate-based systems where crossbred cattle are important. Low-producing animals are often left to graze in harvested paddy fields and are moved to scrub land in the crop season. Dairy production in the country is under stress and milk production is almost stagnant, and the country depends on imports to meet growing domestic demand. Productivity of meat animals in Sri Lanka, especially pigs and goats, is the highest in the region.

Policy makers and development agencies should implement programs related to the livestock sector to raise productivity while taking stock of the future challenges. We can expect a greater concentration of livestock production close to demand centres ie, urban/peri-urban areas, since livestock products are perishable. This may undermine the participation of small-scale producers in the hinterlands. Hence, steps need to be taken to provide infrastructure like modern cold chains for speedier and safe transportation of produce from rural areas to more distant markets. Secondly, policies need to be in place to reduce the intensification of livestock production close to urban centres by taxing industrial systems for environmental pollution while at the same time providing incentives for processing and distribution chains to locate and spread out in rural areas and linking them to production areas on the one hand and demand centres on the other. Land and livestock balances have to be achieved on an area wide framework.

Partners:

ICRISAT : P Parthasarathy Rao  
ILRI/SLP : M Blummel  
NCAP : PS Birthal

Publications:

**Parthasarathy Rao P and Birthal PS.** In press. Raising livestock productivity in smallholder crop-livestock systems in South Asia. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for

the Semi-Arid Tropics; Pusa, New Delhi, India: National Centre for Agricultural Economics and Policy Research and PO Box 5689, Addis Ababa, Ethiopia: CGIAR Systemwide Livestock Programme.

**Parthasarathy Rao P and Birthal PS.** 2007. Markets and institutions for pro-poor livestock sector development. Pages 178-182 in Proceedings of National Symposium on Recent Trends In Policy Initiatives And Technology Interventions For Rural Prosperity In Small Holder Livestock Production Systems. Sri Venkateswara Veterinary University and Indian Society of Animal Production and Management.

#### *1.D.7. Poverty, food security and agricultural growth trends in Southern Africa*

Rationale and objectives of the study: There is evidence to show that broad-based agricultural development is an effective means of reducing poverty and accelerating economic growth (FAO/World Bank, 2001). Agriculture remains a key driving force for economic development in the Southern Africa Development Community (SADC) – a region in which most inhabitants rely on agriculture directly or indirectly as their main source of livelihood. It remains the primary source of subsistence, employment and income for 61%, or 142 million of the region's total population of 232 million. Agriculture accounts for close to 8% of the region's gross domestic product (GDP). Despite the importance of the sector in SADC's economy, agricultural growth rates have been both low and highly variable across the region, averaging only 2.6% per annum in the last decade (Figure 1). Average growth rates in the sector have been almost similar to demographic growth rates of 2.4% over the same period (World Bank 2006). Of the numerous explanations for the sector's poor performance the most significant are insufficient investment in agriculture, poor access to agricultural inputs (especially fertilisers and improved seed) and to markets, and low levels of technology development and dissemination.

These factors have resulted in limited growth in the average yields of key crops and in low labour productivity. Other factors include adverse climatic conditions and HIV/AIDS, both of which threaten the livelihood of farming households. This situation calls for strengthening and transforming agriculture in the region so that it stimulates much needed economic growth and contributes measurably to poverty reduction. Increasing food production will help ensure that food prices remain low creating a conducive environment for the development of a broader commercial economy. In addition, there are bright prospects for expanded commercial production of a wide range of high value agricultural products.

African countries have committed themselves to allocating a minimum of 10% of the budget GDP to agriculture. In addition CAADP, to which all African countries are signatory, are committed to 6% GDP growth rates. This monitoring of growth trends in agriculture is therefore an effort to contribute toward monitoring the trend on an annual basis to be able to demonstrate performance and recommend adjustments accordingly.

Methodology Used: The study made reference to key sources of trends data on agriculture such as the World Bank, FAO, International Agricultural Research Centers such as IFPRI, National Bureau of Statistics as well as seeking expert opinion from well informed practitioners in business and government.

Milestones and Major Findings: Agricultural performance in terms of achieving food security and generating income has not been impressive in southern Africa. For example, yield per hectare for major crops such as maize remains lower than the average in developing countries (2,000kg per ha for SADC versus 8,000kg per ha for developing countries as a whole). Livestock production has increased only marginally in the last decade. The food security situation in the region remains undesirable with about 35% of the region's population undernourished. The average proportion of undernourished people in the region has remained almost constant since the 1990s. Although the net agricultural production has more than doubled in the last four decades, net capita production has declined by 40% over the same period. In addition agricultural growth rate is almost at par with the population growth rate which is undesirable. Several other agricultural growth indicators in southern Africa are showing poor performance when ranked with other developing countries.

Year by year monitoring of similar data sets by SAKSS will help to bring to bear analysis of agricultural growth trends which can then feed into national and regional policy debates.

#### Publications:

**Chilonda P, Machette C and Minde IJ.** 2006. Poverty, food security and agricultural growth trends in Southern Africa. ReSAKSS Discussion Paper No.3 2006. Re SAKSS. Pretoria: South Africa

**Chilonda P and Minde IJ.** 2007. Agricultural growth trends in Southern Africa. Policy brief no. 1. ReSAKSS, Pretoria: South Africa

### **Priority 5C. Rural institutions and their governance**

Priority 5C. Specific goal 1: Identify mechanisms for the strengthening of producers' organizations and for modes of participatory research

Priority 5C. Specific goal 2: Identify new forms of partnerships with NARS, the private sector, public extension agencies, NGOs and producers' organizations, and public agencies from other sectors, such as environment and health to enhance the conduct and impact from agricultural research

**Output 1E. Alternative institutional innovations and typologies to strengthen rural institutions that facilitate and enhance adoption of technological and market innovations and policy recommendations for formal and informal social networks to address vulnerability, gender and social exclusion in SAT farming systems developed and shared with partners.**

ICRISAT is faced with the challenge to identify broad lessons and strategies that facilitate the emergence of viable farmer organizations and institutions that facilitate access to essential services, namely markets and agricultural innovations, and help mitigate vulnerability to shocks or support local agricultural recovery efforts. ICRISAT is working closely with different kinds of farmer organizations in various countries. ICRISAT has also taken initial steps in understanding how such rural organizations evolve and function and how they can provide effective services especially in relation to marketing groups, farmer cooperatives and other commercially-oriented farmer enterprises. GT-IMPI provided critical inputs to develop a framework plan for CGIAR research on System Priority 5C.

#### ***1.E.1. The sociological analysis of social networks (Asia)***

Project Rationale: There is a considerable body of literature on social capital and social networks, which has been published over a relatively short period of time. Each of these have some interesting findings to offer. This concept is found to be useful in understanding how cooperation, collective/group action can help people combat poverty. The focus is on how social networks and relationships can empower people personally and in revitalizing their communities and thus impact on their everyday lives.

A social network can be viewed as a set of concrete interpersonal relations linking the individual to other individuals who are members of diverse systems of groups and categories. A network, even when viewed from the standpoint of a single individual, has a dynamic character. New relations are forged, and old ones are discarded or modified. This is particularly true of rapidly changing societies in which individual choice plays an important role. For an indepth understanding of this concept, it is necessary not only to chart the concrete networks of different individuals, but to relate these different networks to one another, to draw up, a master chart, in a coherent and systematic manner.

Social network analysis will help to more systematically describe different kinds of social relationships that exist and develop within the context of rural communities. Social network analysis is focused on uncovering the patterning of people's interaction. This analysis is based on the premise that these patterns are important features of the lives of the individuals who display them. Social network analysis in general studies the behaviour of the individual at the micro level, the pattern of relationships (network structure) at the macro level, and the interactions between the two. The analysis of the interaction structures that is involved in social network analysis is an important element in the analysis of the micro±macro link, the way in which individual behavior and social phenomena are connected with one another.

Though there is plenty of literature on social networks and their role in influencing decisions, more methodological and conceptual work is needed to understand the network conditions that best help to nurture and support the many aspects of rural communities. The focus of this study is on the SAT poor engaged in agriculture, the marginalized groups especially women.

Appealing to the concept of social capital as networks and relationships, this research will analyze the types of social networks that men and women farmers associate with, the networks that powerful groups have access to, and assess the relationship between all of these. Mapping the network architecture (including networks



developed either through formal organizations, kinship groups, neighborhoods networks, work groups, self-help groups, or informal interactions), will allow us to investigate the flow of information and the functioning of power relations in the village, and envisage how to improve the impact of particular development programs on rural households, in terms of risk-insurance and poverty-reduction. The research will also use a social lens on the dynamics of shocks and how social networks can help in coping with shocks.

Project outputs: The architecture of social networks in the study villages is mapped. This mapping will help us understand how the pattern of ties in a network provides significant opportunities and constraints because it affects the access of people and institutions to such resources as information, wealth, and power.

The research will also help in developing a knowledge base on social networks at various levels that will facilitate informed R & D, policy making, and interventions. This will help in particular to identify local networks already in place that will facilitate layering new innovation intervention; and groups or households that are not socially connected, and thinking about how their needs can be included.

The findings may assist in designing strategies, policy formulation and institutional arrangements for effective intervention. Benefits to the community include increased incomes through enhanced linkages, greater access to resources through altered property rights regimes, and new governance mechanisms based on participation and inclusion of community members.

This project will provide an understanding of the linkage existing between different institutional spheres and between different systems of groups and categories. This understanding can be used for policy formulation to help the rural community help themselves come out of poverty. This might include:

- Training agricultural professionals to work with existing systems of learning and experimenting.
- Identifying local innovation networks already in place before introducing ideas and technology from outside of a community.
- Considering particular groups or households that are not socially connected, and thinking about how their needs can be included.
- Existing programmes to promote rural development in remote areas will continue to be important.

They can become more effective, however, if they build on existing local networks, and make use of the ability of rural communities to develop new processes themselves. Developing effective connections between formal processes and informal local networks is a major challenge. Making linkages that work successfully will be a vital feature of policy support for sustainable rural livelihoods in many areas.

Approach and methodology: The framework for the study is developed with a focus on women as a distinct group. Caste and class may also act as barriers to development in Indian situations. Along with gender, caste and class considerations will also be looked into.

Methodological and design aspects of the project include participatory and inter-disciplinary research involving qualitative and quantitative methods, social network analysis, gender-based social analysis, and needs assessment. It will include mapping of the network architecture for enabling market linkages and social inclusion, improving access to and management of agricultural innovations and livelihood diversification and coping with shocks. The research will also address how and why social networks are fragmented within communities? Which collective benefits could emerge from creation of new links?

To date, empirical research on the factors that affect rural people's ability to engage in various forms of collective action, and on the effectiveness of collective action to improve people's life, is mostly of a qualitative nature. This research proposes to combine quantitative and qualitative analysis in two selected villages - Aurepalle in Andhra Pradesh and Kanzara in Maharashtra, where ICRISAT has been conducting a village-level surveys (VLS) for about thirty years.

Milestones achieved:

- Review of literature on different aspects of social networks and social capital completed. The sociological evidences are documented in a report entitled, "Role of Social Networks in Influencing Decisions: Review of Literature."
- A methodological review of the research on social networks is drafted

- Finalizing methodology for the study – this includes developing a theoretical framework underpinning the concept of social network in empowering rural communities – both men and women; site and sample selection, and developing instruments for data collection
- Preliminary analysis of the data from the survey on “social networks and linkages” undertaken in 2005.

Preliminary findings/Major findings: Analysis of sociological research undertaken during the VLS 1 period. The focus during this period was on social organization and group size. Identification and understanding of anthropological conditions for group action have been a major research focus in ICRISAT’s economics program since the latter part of 1976. This included a study of literature regarding cooperation for agricultural production, examination of particular cases from India, and study of relevant anthropological work on group size and function (Doherty and Jodha 1979, Doherty 1980) and on agricultural production, social status and intra-compound relationships (Helga Vierich; Koho, Burkina Faso). Some important findings include:

- how much cooperation is to be expected from different sizes of groups of farmers under different conditions
- whether group ownership and control can be considered in a particular case or whether individual ownership and control is necessary
- close links between the village institutions that organized economic activities and agricultural performance
- rate and impact of the adoption of new technology was found to vary by ethnic group
- adoption of new technology – increased productivity and privileges accorded to social status brought access to labor resources

*Analysis of VLS 2 data on social networks and linkages*

The variables considered for the analysis include: membership in organization by type of organization, degree of participation, benefits from the groups; information networks and services . These are compared across caste and gender. Results from two villages - Aurepalle and Kanzara - are compared in this analysis.

In Kanzara it was found that there are two dominant groups existing in the village – the credit society group (dominated by male members of the community) and the women self help groups. In Aurepalle, a contrasting picture was seen – there are many networks/groups operating in the village and it was observed that people belonged to multiple groups/networks. Women belonged to the self-help groups as well as the credit society, men were members of the credit society, and they were members of the education committee and so on. This result raises some questions- what are the reasons for people of Aurepalle to form diverse networks and be a part of them? Are there cultural, social, economic or political reasons as to why people of Kanzara are not coming together to form new networks? These can be addressed through the social network analysis.

The analysis of the intersection of gender and caste in the network formation in Kanzara reveals that men from the forward caste belong to the credit society while the women from the backward and scheduled castes are coming together to form the self-help groups. The issue then is to understand what the factors that inhibit men and women from different social groups to become members of different groups and networks are. On participation in groups the preliminary analysis revealed no active participation by men and women in both the villages. Is this so because of the power structure that exists in the village? A social networks analysis may help us to identify these and such reasons. Both men and women farmers perceived access to credit as the main benefit from group membership. Probing on the important groups approached for access to services, the Kanzara data revealed that the gram panchayat was the most sought after group by both men and women, and more for issues related to water and its availability.

Information of this kind will help in understanding the emergence of connections/ties and also help in catalyzing the tie formation. For example, knowing where the connections are, and are not, allows a researcher/development planner to influence local interactions. This is particularly important in introducing interventions – health, agricultural, market or policy - as knowledge of the key nodes plays an important role in understanding what flows throughout the network. Will influencing a small number of well-connected ties like the women self-help groups or accessing the top persons (eg, sarpanch) result in better outcomes? If so, social network analysis will help find answers to why, when and how this will occur.

Partners:

ICRISAT : MCS Bantilan, R Padmaja  
IIT-B : D Parthasarathy, Rowena Robinson, K Narayanan

Publications:

**Padmaja R, Parthasarathy D and Bantilan MCS.** 2007. Role of social networks in influencing decisions: a review of literature. Progress report. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

**Padmaja R, Parthasarathy D and Bantilan MCS.** Forthcoming. Social networks in technological change: focus on gender and agricultural technological innovations. Draft report. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

***1.E.2.. Rural institutions and policies for integrated watershed management in semi-arid India: Strategic issues and priorities***

Degradation of agro-ecosystems and declining sustainability are major concerns for agricultural development in many poor regions of the world where livelihoods depend on exploitation of natural resources. This is especially so in the semi-arid areas where water scarcity, frequent droughts, soil degradation and other constraints lower agricultural productivity and the resilience of the system. Community-based integrated watershed management (IWM) is therefore being recognized as a suitable strategy for improving productivity and sustainable intensification of agriculture in drought-prone regions. This concept ties together the biophysical notion of a watershed as a hydrological unit with that of the community and its institutions for sustainable management of land, water and other resources.

Evidence shows that IWM has a potential to address poverty, livelihood vulnerability and environmental challenges prevalent in rainfed and drought-prone regions. While technological options for watershed development are well understood, there is limited knowledge and experience on institutional and organizational issues required for its management. This is proving to be the main bottleneck for effectiveness of many of the watershed programs. Watershed management therefore calls for policy and institutional interventions that enhance collective action among the diverse resource users.

Future watershed policies need to be consistent, especially those related to agricultural input and output marketing, poverty reduction, safety nets, infrastructure and power. Along with suitable policies and institutional arrangements, there is a need to develop pro-poor and innovative watershed interventions. These include a) Improvement of small on-farm water storage structures; b) Micro credit systems; c) Improved livestock production; d) Promotion of horticultural crops; e) Bio-fuels on degraded lands; and f) Marketing of environmental services

Partners:

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CESS : V Ratna Reddy

Publication:

**Reddy RV, Shiferaw B, Bantilan MCS and Wani SP.** 2007. Rural Institutions and Policies for Integrated Watershed Management in Semi-Arid India: Strategic Issues and Priorities. Brief Note. Nizamiah observatory, Begumpet, Hyderabad: Centre for Economic and Social Studies and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 4 pp.

***1.E.3. Collective action and property rights for poverty reduction in watersheds (Asia)***

Project rationale: Collective action (CA) lowers the transaction costs for the farmers in the rural areas. It enables them to make investments to improve both the private and common property resources, which is otherwise a costly affair. But, the property rights to both privately and commonly held resources need to be well defined and respected. While some communities/societies engage in CA successfully and benefit from such activities, others fail. This study makes an attempt to (a) conceptualize and measure CA for watershed management in India, and (b) identify the determinants of successful CA.

Methodology: Eighty-seven watersheds were randomly selected from six districts [representing two from each of the low (less than 700 mm), medium (700 mm to 900 mm) and high (more than 900 mm) rainfall zones of the state of Andhra Pradesh in India]. All the sample watersheds were implemented following the 1994 guidelines

for watershed development. Data were collected at the community level from leaders, user groups and key informants on a range of issues that characterized the village and the watershed groups.

The main hypothesis of this study is that, the level to which communities can act collectively varies. The primary data of the proxies was collected. Different variables representing CA were aggregated. The scoring coefficient was obtained through the principal component factor analysis.

Conclusions: A huge variation of the capacities to engage in CA exists among the sample watersheds. The following are a few factors, which explain the variation:

- High levels of CA exist among the experienced groups. The finding supports the hypothesis that individuals of the group develop trust and are more forthcoming to participate in CA irrespective of the kind of goal pursued.
- Presence of conflict resolution mechanisms improves the CA.
- Distance to input and output markets are positively and significantly associated with the LCA. Selling the produce and buying the inputs significantly minimizes the costs

Partners:

ICRISAT : B Shiferaw, MCS Bantilan  
Humboldt University : Martina Padmanabhan, Srigeri Srinivas Reddy

Publication:

**Reddy SS.** Forthcoming. Equity and poverty issues in watershed development projects in India. PhD dissertation. Humboldt University of Berlin. Institute of Agricultural Economics and Social Sciences Department of Resource Economics.

*1.E.4. Institutional arrangements for common watershed management of the semi-arid tropics in India*

Project Rationale: This study aims to analyze institutional arrangements regarding their contribution to a successful implementation of watershed projects in the semi-arid tropics. In three in-depth case studies we discuss the impact of market relations between watershed appropriators, governmental interventions and the local community on the implementation process of watersheds. While in all three cases no market based relations between watershed appropriators existed, governmental assistance in terms of funding and administrative support seems to be essential for the construction of watersheds. All three cases show a lack of community involvement, which led to emerging possibilities for rent-seeking processes and reduced the local appreciation of the watershed investments. However, the most successful project featured a more widespread distribution of benefits, a more homogeneous income and caste structure and a lower employment of the local elite in the watershed implementation process. Furthermore, it also seems to be of importance that farmers are willing to continue farming regardless of whether they produce for own consumption or for regional markets as well as that all villagers were able, irrespective of their occupation, to benefit from the watershed project. For the development of further watershed programmes it seems to be more promising to implement more market competition within the application process for watershed programmes. Communities should be encouraged to organize themselves to elaborate concepts for watershed projects and to compete with such concepts with other communities for a certain state budget. This may lead to a more efficient distribution of public funds and a stronger community involvement. Moreover, a more indirectly governmental support in terms of trainings for farmers to enhance their awareness for monoculture and negative external effects of irrigation water overexploitation as well as the provision of regionally adjusted seeds and improved animal genetics seems to be promising as funds spent only directly on watershed constructions. Further indirect governmental assistance could be given as financial and administrative support for founding agricultural co-operatives and the use of water use efficient crops.

In this paper unsuccessful watershed implementation and management is seen as a problem of common pool resource provision. It is argued that an effective implementation and management of watersheds in villages is mainly hampered by coordination failures between different appropriators of the common pool resource. To overcome these coordination failures appropriate institutional arrangements have to be provided. According to the recent literature market approach, central government, and community governance are seen as institutional alternatives to overcome such coordination failures in common pool resource provision.

Methodology: The data collection was mainly based on qualitative and quantitative methods. We conducted in-depth case studies in three watershed villages in the Mahabubnagar district in Andhra Pradesh, India. Household

interviews, key-informant interviews with the village president, village secretary and persons responsible for the watershed implementation as well as focus group meetings with villagers who directly benefit from the watershed were conducted to analyze the organization of the watershed implementation process, the watersheds' impact on the socio-economic situation of the villagers and the social cooperation between villagers.

Findings and Conclusions: This study analyzes three institutional arrangements: market relations, governmental interventions and community governance regarding their capability to contribute to a successful watershed management in villages of the semi-arid tropics of India. Results are based on in-depth case studies in three villages (Dokur, Sripuram and Zainallypuram) of the Mahabubnagar district.

In all three case studies no market relations between appropriators in terms of irrigation water extraction and use was found. Governmental funding was in all three villages essential to encourage the creation of local watershed institutions and the constructions of soil and water conservation facilities. However, all three analyzed projects show a lack of community involvement, which in Dokur and Sripuram led to rent-seeking activities starting from local elites and to a low appreciation of watershed constructions, since villagers were often not able to comprehend the scope of profits such constructions may yield. In addition to the field constructions, in two of the watershed projects subsidies were also given to local saving groups. Such support emerged as even more promising than investments in watershed facilities, because the latter, due to a long term drought period, were often not able to function properly. In contrast, saving groups enabled inhabitants to spend sources more precisely according to their needs. Furthermore, they provided landless people or villagers, who do not possess any watershed constructions on their fields, with the opportunity to benefit from the watershed project. The provision of additional jobs for local labour in the watershed project have in addition to the positive impacts on labour incomes also negative bearings on farm households, since the latter realized in Sripuram and Zainallypuram a strong increase of local wages and a loss of job motivation of local labour.

According to OSTROM's (2005) determinants for a successful community management of watersheds, the project implementation in Zainallypuram exhibited a more detailed response to local needs and conditions than in Dokur and Sripuram. Although there was a lack of community involvement in the implementation process of all three watershed projects, the appreciation of the watershed project in Zainallypuram was higher. Watershed constructions there were done more properly and benefits were distributed more widely. Therefore, villagers were able to recognize resource and income improvements more strongly. Furthermore, the more homogeneous income and caste structure as well as a lower employment of the local elite in the watershed project may also have contributed to a more successful watershed implementation in Zainallypuram. In contrast to other studies on watersheds, our results indicate that a close connection to agricultural markets seem to be less important, since the majority of farm households in Zainallypuram were subsistence farms. It is rather more important that farmers are willing to continue farming regardless of whether they produce for own consumption or for regional markets. In the case of Zainallypuram, villagers were also able, irrespective of their occupation, to benefit from the watershed project, eg, in terms of saving group loans, which were employed to found new sources of income.

It generally seems to be more promising, since the implementation of measurement systems for irrigation water to enforce a stronger market based relationship between watershed appropriators is often combined with high transaction costs, to implement more market competition within the application process for watershed programmes. Communities should be encouraged to organize themselves in order to elaborate concepts for watershed projects and to compete with such concepts with other communities for a certain budget provided by the state. This might lead to a more efficient distribution of public funds and a stronger community involvement. Furthermore, governmental funds should be spent more indirectly in terms of trainings to enhance farmers' awareness for monoculture and negative external effects of irrigation water overexploitation. Also the provision of seeds, which is more adjusted to the local environmental conditions as well as improved animal genetics, could be subsidized by the state. Other indirect governmental support could be given in terms of financial and administrative support for agricultural co-operatives to set up incentives for local farmers to purchase inputs and sell products commonly in order to improve their market power. At last, the use of water use efficient crops can be supported by the government, too. However, the latter should not only be recommended on trainings, but it seems to be more promising to set up economic incentives for the cultivation of such crops by facilitating the market access for such crops.

Partners:

Leibniz-Institute for Agriculture development in Central Germany and Eastern Europe (IAMO), Halle : Andreas Gramzow, Martin Petrick,

Publication:

**Gramzow A** and **Bantilan MCS**. 2007. Institutional arrangements for common watershed management of the semi-arid tropics in India. Draft paper. Under review

***1.E.5. The effects of identity and social networks on investments and market participation behavior: An Analysis from Rural South India***

The research analyses quantitatively the effects of identity and social network on educational investment, agricultural technology adoption and market participation decisions, and differentiates these effects along pathways (Social learning, discrimination, social norms, imitation, price- scale effects on the agent's resource constraints) using data from six villages in the Indian states of Maharashtra and Andhra Pradesh. The villages selected for this study have been studied before by ICRISAT in its Village Level Studies (VLS) during the period 1975-1985, and detailed background information and data on household and village level characteristics are available.

The dissertation research theory thereby addresses an important gap in the development economics literature. Recent studies in economics acknowledge the importance of (non-productive) identity and social networks in economic decision-making. Social networks and identity mediate the mapping from the resources into outcomes through their effects on preferences, constraints and expectations, thereby influencing economic decisions such as participation decisions. However, none of the existing studies have differentiated these effects along the following pathways: learning from one's contacts (often referred to as social learning), discrimination (ie, prices or access to certain goods is different for members of differently identified groups), price-scale effects (ie, the value/cost of a good depends on the number of users), social norms (ie, a rule in a certain locality that is socially enforced through sanctions), imitation (ie, copying the actions of certain people one observes), and easing of labor, capital and credit constraints (eg., friends and family give a helping hand on the land during harvest, lend machinery or provide loans). Differentiating these effects along these different pathways is important from a policy perspective as the right strategy to stimulate educational investment, increased and quicker uptake of promising technologies, and market participation depends fundamentally on the structure of the decision process at household level.

Concretely, the goal of research is threefold: first, to contribute to the methodological development of the field of development economics by introducing a set of relatively new-data collection techniques, such as 1) the within-sample random technique where individuals who are part of a random sample are randomly matched with other individuals within the same sample and asked about past and present links, their willingness to establish a (hypothetical) link with him/her and their perception of his/her ability and social and cultural attributes; 2) the collection of information on subjective expectations; and 3) the capacity to mobilize information by conducting small experiments: second, to develop an identification strategy to separate the different social network and identity effects in the data: and third, to make the data and the data collection methodology publicly available, thereby ensuring that the policy implications of this study extend beyond the Indian case.

Collaborating Institutions and Scientists:

Cornell University : Annemie Julie Maertens, Christopher Barrett  
ICRISAT : KPC Rao, MCS Bantilan

***1.E.6. Institutional and organizational innovations for accessing markets and empowering communities in semi-arid Kenya (ESA)***

Rationale: Market transactions in rural areas of sub-Saharan Africa (SSA) are usually small, because the markets are thin and point-to-point transportation of commodities is difficult. The prices offered are not competitive and volumes traded are usually season dependent. Where market infrastructure is weak and under-developed, liberalization and structural adjustment policies have not been able to improve market access; and the private sector has failed to make the investments needed for proper and effective market coordination.

Nevertheless, the new economic environment has opened a window of opportunity for farmers to harness market opportunities, diversify into tradable products and reduce dependence on subsistence farming. The

removal of market barriers increased competition and allowed farmers to choose the buyers of their outputs and the suppliers of key inputs. Despite these positive developments, markets have not been able to spur commercialization of smallholder agriculture that could provide incentives for increased production and investments for managing production risks. Hence, smallholder market participation and marketed surplus remain very limited. High transaction costs and the inability of smallholder farmers to consistently supply consistent quality products remain key impediments to the realization of the benefits of liberalization, while geographical dispersion has limited market development. These factors have deprived farmers of the incentives to produce high value differentiated products with desirable traits.

Under enabling conditions, the Producer Marketing Groups (PMGs) and similar farmer organizations can facilitate market access to the poor through horizontal and vertical coordination of production and marketing activities. They can help shorten the long and complex marketing channels that prevail in many rural input and output markets by directly linking smallholders with the upper end of the value chain. This can help reduce transaction costs and increase the share of the consumer price reaching small producers. The experiences in semi-arid Kenya highlight several interlinked constraints that call for new approaches and policy interventions to facilitate and support development of rural institutions.

#### Objectives:

- Identify major determinants of farmer participation in collective marketing or community-based watershed management and assess how collective action (CA) contributes to poverty reduction
- Suggest alternative institutional arrangements and organizational innovations that contribute to viable and sustainable CA for grain marketing and/or community-based watershed management

#### Major outputs:

- The key determinants of CA for marketing of grain legumes in eastern Africa identified and integrated into development and policy process
- Gaps in current policies and future policy needs for viable CA in grain marketing identified and promoted
- The role of property rights, existing policies and institutional set ups and their influences on CA understood better and lessons communicated
- Strategies for enhancing the participation of farmers and women groups in collective marketing developed and promoted

Methods: Based on a review of experiences across SSA and a case study in semi-arid Kenya, this study investigated the role of market institutions and producer marketing groups (PMGs) in enhancing the market opportunities for the poor through better coordination of production and marketing functions, and facilitating contracts with market agents along the value chain. Data was collected at group, village and individual household levels. The collected data (both qualitative and quantitative) was analyzed using standard statistical and econometric methods to address key policy questions and research objectives. This helped to understand the role of different variables identified in literature on participation in collective action and also gave insights into how poverty in terms of endowment of certain livelihood assets affect participation in collective action.

Milestones: Data collection and analysis was completed. Several journal papers, working papers and a book chapter have been completed and published or they are under final stages of review as indicated in the publications section. The work was complemented by a PhD student from Michigan State University who joined in early 2007 to work on institutional innovations for reducing transaction costs in grain marketing in Kenya. The PhD student has already completed field surveys in eastern and western Kenya with a survey of over 800 farm households and 80 farmer groups. Two M.Sc. students from the University of Nairobi were also supported to research the role of social capital on technology adoption and market participation. Analysis of the data by the Ph.D and M.Sc. students is underway

Major findings: The analysis of collective marketing in Kenya showed that the functioning of markets is constrained by high transaction costs and coordination problems along the supply chain, but PMGs could provide new opportunities for smallholders through vertical and horizontal coordination of production and marketing functions. Marketing groups pay 20-25% higher prices than other buyers to farmers while participation was also positively correlated with adoption of improved dryland legume varieties, crops not targeted by the formal extension system. The effectiveness of groups is determined by levels of participatory decision making, member contributions and their initial start-up capital. The likelihood of membership in PMGs declined with farm size indicating that the incentive for participation is higher for small-scale farmers who face

high transaction costs. The benefits of participation are however directly related to the amount marketed through groups. The choice of the PMG channel was influenced by inability to pay on time due to capital constraint faced by the groups. Hence, lack of access to credit and finance is a major constraint that limits competitiveness of marketing groups. Sustainable transition of PMGs into farmer cooperatives will require public interventions and investments in complementary institutions to improve farmer access to technologies, capital and market information.

On the other hand, collective action in watershed management showed that scaling up of the already known efficient and effective technological and institutional options for watershed development options are a big problem. Current CA has focused on resource management and production while largely neglecting input and output marketing, which could lead to substantial benefits for smallholder and marginal farmers who face high transaction costs in marketing their small marketable surpluses as evidenced with PMGs in Kenya. There is need for appropriate policy to reduce the gap between producer and consumer prices and enhance distributional benefits of watershed benefits.

Partners:

ICRISAT

Egerton University

Michigan State University

University of Nairobi

Publications:

**Shiferaw B, Obare G and Muricho G.** 2007. Rural institutions and producer organizations in imperfect markets: Experiences from producer marketing groups in semi-arid Eastern Kenya. Paper presented at the CAPRI policy conference, Feb 28 – March 2, 2007. Entebbe, Uganda.

**Shiferaw B, Obare G and Muricho G.** Forthcoming. Leveraging institutions for collective action to improve markets for smallholder producers in less-favored areas. Under review. African Journal of Agricultural and Resource Economics.

**Shiferaw B, Obare G and Muricho G.** In press. Rural market imperfections and the role of institutions for collective action to improve markets for the poor. Natural Resources Forum.

**Shiferaw B, Obare G and Muricho G.** 2007. Can rural institutions for collective action overcome market imperfections for farmers in less-favored semi-arid areas? Contributed paper presented at the African Association of Agricultural Economists Conference, 20-22 August 2007, Accra, Ghana

***1.E.7. Development of a conceptual framework for monitoring and evaluation of poverty in Niger (WCA)***

Rationale: Niger, like many countries in West and Central Africa, is engaged in the process of decentralization of its economy. However, the process faces difficulties in implementation due to the lack of experience in management, low ability of the local managers, but also the insufficiency backstopping of the young communes to acquire suitable instruments and appropriate mechanisms to monitor, evaluate and lead their development process.

The community Monitoring and Evaluation (M&E) system is intended to be useful to local evaluation committees for monitoring progress of their own projects and revising their development plans. The system is also intended to provide information to other stakeholders, such as PAC regional and national coordinating units and government agencies. Especially for the latter purpose, but even for the former one, development of a common conceptual and methodological framework, linked to the national M&E activities, is needed to facilitate the ability of stakeholders to draw valid conclusions from project experiences. This is not to argue that a one-size-fits-all approach to M&E is necessary. There are likely to be differences across communities in the indicators that they choose to monitor and in how those are measured and evaluated, depending upon what outcomes and activities their own projects seek to address. Nevertheless, it is highly desirable to use a common conceptual framework and set of indicators to the extent possible and consistent with the objectives of the different community projects, based on consultation with communities that are implementing land rehabilitation projects and with other stakeholders. Some of the information collected at community level would then be able to feed into the regional and national level M&E systems and the national poverty reduction strategy, and could be used for comparative analysis. This activity will be a pilot scale activity (ie, implemented only in the PAC



communities pursuing SLM activities in the first phase), and the lessons learned would contribute to revision of the design implemented in subsequent phases (and possibly for other programs).

Although an M&E system has been established within PAC at the national and regional levels and training has been provided to many communes in M&E methods, the community M&E system for PAC is not yet fully functioning. According to various stakeholders interviewed at national, regional and local levels<sup>5</sup>, the constraints to effective functioning of the community M&E system include the following:

- Absence of a conceptual framework and methodology for conducting M&E at the community level;
- Local stakeholders' lack of understanding of the role and importance of M&E;
- Lack of practical training and technical support for local M&E; training and data collection tools not adapted to local environments;
- Lack of internalization/ownership/motivation of local stakeholders in conducting M&E activities;
- Costs of M&E activities (eg, transport costs to scattered villages) and lack of resources to support these activities at the local level;
- Limited capacity at commune level to support M&E due to their recent establishment;
- High rates of illiteracy and differences in local languages,
- Lack of a culture of community action; people more focused on private gains;
- Migration – some local leaders involved in M&E often not around due to seasonal migration.

Beyond the constraints mentioned above, several other requirements and issues for the community M&E were raised by various stakeholders:

- The community M&E needs to monitor indicators that support the national Poverty Reduction Strategy (PRS), the national PAC monitoring system, and regional and local development plans. Information collected in community M&E at the village and grappe level should be provided to communes, departments, regions and national level, should be consistent with indicators needed at those levels, and should be comparable across communities and regions to the extent possible.
- Information from M&E activities should also be useful for local communities, be based on consultations with community members and be suited to the activities that they are conducting. The information collected should be as simple and easy to collect as possible, and information should be shared across regions and communities to facilitate learning from experiences in other locations.
- The primary focus of capacity development for community M&E should be at the commune level, since this is the focus of decentralization efforts and local development planning, and where the primary responsibility lies for implementing community M&E.
- The conceptual framework and methodology developed for community M&E should be useful not only for monitoring PAC activities, but for all local development activities. Consulting with and obtaining buy-in of other development partners besides PAC in the community M&E system will therefore be quite important.
- How far the community M&E system should go in assessing the outcomes and impacts of development activities is an important issue, and one that stakeholders do not clearly agree on. While all stakeholders appear to agree that it is important to monitor completion of program activities (eg, the number of trees planted, demi-lunes constructed, health centers and schools constructed, etc.), not all agreed that it should be the role of the community M&E system to monitor the impacts of such activities on outcomes of interest (eg, increased agricultural production and income, improvements in environmental conditions, health and literacy, etc.). Some argued that other methods would be better suited to assessing such downstream and longer term impacts, such as use of baseline and follow up surveys, remote sensing, etc. This project will combine survey methods with community level M&E activities.

Approach and methodology: The methodology used for the community M&E is impact pathway analysis (Douthwaite, et al. 2003; Springer-Heinze, et al. 2003). Using this method, various impact pathways of particular types of micro-projects and activities were identified through consultations with stakeholders in

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<sup>5</sup> These interviews and discussions were conducted jointly by John Pender of IFPRI, Jupiter Ndjeunga of ICRISAT, and Mohammed Assadeck, National Coordinator of M&E for PAC (during a project planning and preparation field tour in May 15 to 26, 2006 which included meetings with PAC officials, government officials and other development partners in Niamey and visits to PAC and other program offices and several communities in the regions of Tahoua, Agadez, Zinder, and Dosso).

villages and at higher levels. Such impact pathways and indicators were identified for different types of micro-projects through consultations with pilot communities during this project, and then used as the basis for developing a protocol for collecting information on indicators for each type of micro-project. Consistency between the indicators identified through this consultative process and the indicators needed for the PRS and other planning frameworks were verified. For most micro-projects, many of the ultimate impact indicators, such as improved incomes and health, will be similar across micro-projects and consistent with the PRS indicators.

We selected three communes representing different agro-ecologies, farming systems and land degradation issues as pilot communes for this project. The communes are the commune of Bibiyergou (mostly agro-pastoral based), the commune of Tanda (crop agricultural based) and the commune of Niamey V in the peri-urban area. These communes were chosen from the regions of Tillabéry, Dosso and Niamey to facilitate access of the M&E team leader to the study sites.

Consultations with community members, training activities, and testing of the community M&E protocol were conducted in several villages in each selected commune. At the commune level, the major instrument was the COMMUNE DEVELOPMENT PLAN. Structured surveys were conducted to collect data and compared to potential baseline data. This was meant to assess changes that have occurred since the implementation of activities in the local development plans. This served as a means to show local actors the relevance of such undertakings.

**Major findings:** This study contributes to this process by developing a conceptual framework on monitoring and evaluation of poverty in Niger. This tool is unique and participatory in that it involves the population in the development of a monitoring and evaluation system that will allow them to better appreciate the quantitative and qualitative indicators, the real changes occurring in their environment. The major player who is the community must develop an evaluation culture for more engagement in the improvement of their living conditions.

The results of this study show that to develop a local monitoring and evaluation framework, it would be necessary to follow 14 essential stages of which (1) the analysis of the Commune Development Plans (PDCs), (2) the updates of PDCs with the local partners, (3) the development of the impact pathways, (4) the analysis of the relevance of the indicators, (5) the validation of the logical framework with the local actors, (6) the collection of data for initial values through baseline surveys, (7) the identification of the actors and institutions at the local level, (8) the development of the tools for data collection, (9) the training of local actors, (10) data-gathering, (11) the entry of the data, (12) data analysis and interpretation, (13) information feedback and the (14) data utilization and dissemination.

The current PDCs comprise a certain number of insufficiencies. As regards to the logical framework, the relationship between the activities, the results, sub-objectives and objectives are not clearly established as well as the hierarchization of the objectives and/or the outcomes. Sometimes the outputs are presented ignoring the outcomes and impacts.

The need for carrying out a baseline study after the indicators are well identified is clearly established. In this study, the baseline study was carried out before activity planning. It was noted that the baseline study was elaborated on the basis of indicators of the Rural Development Strategy (SDRP) whereas the majority of the indicators in the PDC do not always coincide with those of the SDRP. This implies that at the time of the development of the logical framework, only output indicators are reported and not outcomes and impacts. The indicators do not necessarily coincide with the activities envisaged in the PDCs and the logical framework misses essential initial values to follow and evaluate the development activities or even the performance of the communes.

The reinforcement of the local capacity to collect, analyze and disseminate information is one of the pillars of the process for developing and implementing local monitoring and evaluation systems. This study showed that the average number of school years of the local actors able to fill the survey sheets in an exhaustive and coherent way was estimated to 10 years of schooling. This implies that the communes must have access to human resources able to do this work. Understanding that the resources of several communes are limited (for the example of the commune of Tanda where human resources were not sufficient to cover all the villages. Only eleven enumerators to cover the 28 villages), the judicious use of other human resources in the communes following the example school teachers or other civil servants proves to be necessary.

The reinforcement of the communes in physical and material infrastructures is essential in this process. The majority of the communes do not have access to energy in the form of electricity or power generating units to run equipment or computers necessary for data processing, analysis, synthesis and diffusion of the results. It is only the peri-Urban Commune Niamey V, that has these tools because it forms part of the political capital of Niger.

The local actors are able to collect a number of monitoring and evaluation indicators of poverty that can be used at the local level for managing their local development initiatives and to feed local information in the M&E at higher levels such as the Poverty Reduction Strategy at the national level. It would be necessary to think of an interface with the local level and the decentralized national structures of monitoring and evaluation.

The results of the study also showed the limits of the voluntary help. Indeed, the motivations and incentives of the local actors can constitute a bottleneck to the implementation of the monitoring and evaluation framework. Indeed, the participation of the local actors at various stages of the implementation was not done without financial rewards. This may be explained by the fact that intervention of the various projects in rural areas created a dependency syndrome and now the local actors cannot perform without rewards. The appropriation of this M&E tool still remains a challenge.

The anchoring of the local M&E system with other existing M&E at the national level and in particular that of the SDRP remains a challenge. Indeed, the M&E of the national structures do not have operational structures at the local level that could facilitate the interface between the local M&E and those at the national levels.

Scaling-out and up the local M&E at the national level involves important costs. The estimated cost to scale-out and up the local M&E is estimated to about 2 million USD for the first year with recurring costs estimated at 1 million USD the 4 following years. This results on average in an annual investment of about 7500 USD per commune during the first year with an annual recurring cost of 3650 USD during the 4 following years. When compared with the weak financial base of the majority of the communes, it is difficult for them to consider the financing of such a tool from their own resources. Thus, government subsidies in Niger can be largely justified on this case.

#### Partners:

Monitoring and Evaluation Units of the different Ministries in Niger

The communes

The rural development projects (PAC, LUCOP)

#### Publication:

**Noma DA, Ndjeunga J, Pender J and Gaoh Sani MA.** 2007. Development of a conceptual framework for monitoring and evaluation of poverty in Niger. Paper presented at the Workshop on Monitoring and Evaluation and Impact Assessment of Land Management Programs in Niger, 18-19 October 2007, Niamey, Niger. BP 12404, Niamey, Niger: International Crops Research Institute for the Semi-Arid Tropics.

### **Priority 5D. Improving research and development options to reduce rural poverty and vulnerability**

**Output 1F. Changes in household economies in SAT Asia from 1975-2007 described, from which a policy package of management strategies (both ex-ante and ex-post) for mitigating the impact of risks inherent in rainfed agriculture is developed with associated capacity building for partners and policy makers in SAT Asia and new knowledge shared with partners.**

*MTP Output Target 2007 1.6.1*

*Comparative study contrasting current with past VLS key findings drafted*

#### ***1.F.1. Microlevel assessments of shifting livelihood strategies in the rural SAT using VLS approach in India ongoing (Asia)***

Another 25 percent of the internal targets listed in MTP 2007-09 were achieved during 2007, bringing the cumulative total of achievement to 50 %. The data collection work in the Village Level Studies (VLS) was continued by high frequency method up to 30th June, 2007. The endowments of the sample households as on 1st July, 2007 were collected during July and August, 2007. A census of all households in the six villages was completed in September, 2007. The four monthly round on health module was completed in October, 2007. The

participation of sample households in the government programs during 2006-07 was recorded in November, 2007. The half-yearly round will be conducted starting from December, 2007 after the harvest of Kharif crops. All the data collected so far were input and datasets on some of the modules were already sent to Donors (World Bank). The datasets belonging to the remaining modules will be finalized and sent to the World Bank by the end of December, 2007 as per the contract.

Project rationale: The first generation Village Level Studies (VLS) were suspended in 1985. During the 17 years between 1985 and 2002, many changes have occurred in the markets, institutions, technologies and policies. Aggressive subsidization by the government hastened the shift of coarse grains to superior cereals. This period also witnessed a globalization of agricultural commodity markets. The relative prices of the coarse grain crops have dipped and their cultivation has largely become a non-viable proposition. Due to all these sweeping changes, farmers were moving out from the farming and taking-up the new avenues in the non-farm sector.

Project objective: Micro-level assessment of shifting of livelihood strategies in six VLS villages

Approach and methodology: The methods used for analysis in this basic report are mainly tabular. All the information collected has been tabulated and was subjected to preliminary analysis.

Milestones:

- Review of literature
- Data collection and data entry
- Data analysis
- Report preparation

Preliminary findings/Major findings: The study brought out that the joint families, which were dominant during 1975-84, gave way to more nucleated families, bringing down the average family size from 8.37 in 1975-78 to 5.38 in 2001-04. The family size showed a direct relationship with the size of holding, with the labor households having smaller sized families and large farm households having the biggest families. The literacy levels also increased with the size of land holding. But, among the younger groups, there was hardly any differentiation in the literacy levels. It points to the potential that education can be a great leveler to overcome the socio-economic and class differentiations in the future.

In 1975-78, most of the households in the sample depended on farming as their major occupation. But the occupational structure had become more diversified in 2001-04. This was more so in case of Andhra Pradesh villages, which are more prone to droughts and water scarcity. As crop and livestock enterprises failed to provide enough income for their sustenance, households owning less land looked for alternative occupations that could provide them with more reliable income. Some of the better educated households in Maharashtra could earn a major chunk of their family income from the service sector. Still, those who owned more land depended on farming as their major source of income. Smaller family sizes, better literacy rates and more diversified occupational patterns have placed the households in VLS villages in a position to attain a rapid development on many pathways than two and half decades ago.

The households had less land to operate in 2001-04 when compared with the position in 1975-78. Irrigation made a big difference in changing the fortunes of households in the VLS villages. Maharashtra villages improved their position due to a better access to surface irrigation while the Andhra Pradesh villages became much worse-off due to setbacks in irrigation. Increase in asset values helped the households for investing in education or business by disposing a part of their land. For the poorer households, the only pathway for development lies in encashing the opportunities in the labor markets.

The cropping patterns in the VLS villages have undergone drastic changes in the last three decades. The importance of cash crops increased in all the villages. The area share of sole crops of food grains in the total area under sole crops came down from about 75% to about 35%. In case of intercrops; there was a steeper decline in the share of food grain crops.

The productivity levels varied between regions and crops. Either due to better soils or irrigation support, Aurepalle recorded better yields than Dokur; Shirapur fared better than Kalman; and Kanzara performed better than Kinkheda. While the yield levels in 2001-04 were better than those obtained in 1975-78, they were still low when compared to the yields recorded under irrigation. Drought remained the most dominant constraint for crop production in the VLS villages. Pests, diseases, weeds and excess rains also constrained the performance of

selective crops. Progressive farmers, relatives and friends still remained the most important sources of information, particularly relating to agronomic practices, in the VLS villages. Input dealers hold sway over farmers in providing information relating to improved seeds and plant protection chemicals. Extension officers had a prominent role in supplying information about technology only in Solapur villages.

Most of the crop produce was sold in the market. Even in case of landless labor households and small farm households, the bulk of the produce was sold in the market around the time of harvest. Lack of storage facilities or immediate need for cash might be prompting them to sell a major part of the produce at the time of harvest. The integration of markets and reduction in the transaction costs had enabled them to have a greater market orientation than the subsistence orientation, which was the dominant motive three decades ago.

Due to steadily increasing costs of production and stagnant product prices, crop production has become non-remunerative even when the productivity levels went up to some extent. Because of high incidence of input subsidies, the predominantly irrigated crops are still profitable, but a majority of the rainfed crops turned out to be non-remunerative. The profitability of crops improved with the size of holding in the VLS villages. Variability in crop performance between seasons was quite high in all the villages. Farmers made profits in less than one-third of the plots and did not recover even variable costs in more than one-third of the plots.

The livestock sector is believed to be having a stabilizing effect on the incomes of the farmers in the dryland areas. But the economics of livestock enterprises in the VLS villages do not support this belief. Even when only the variable costs were considered, many of the enterprises are either loss making or with little returns over variable costs. Rearing of buffaloes was more profitable than the rearing of cows. Perhaps because of a limited number of draft animals, the returns to the maintenance of draft animals appear to be attractive. The rearing of small ruminants was profitable in all the villages due to a rapid increase in the meat prices. Thus both the crop and livestock enterprises are not much profitable to the households in the VLS villages. There is a constant search for alternatives by the households to move out of crop and livestock enterprises. There is also an emphasis by the farmers to reduce their dependence on rainfed crops by investing in water exploration to capture the input subsidies associated with irrigation and to stay afloat.

As the incomes declined from agricultural enterprises, sample households relied more on non-farm activities to generate incomes needed for the households. Non-farm labor income increased only by a small proportion and it has still not emerged as a major source of income to rural households. But the other non-farm activities like business, salaried jobs, rental incomes, interest on savings or money lending and self-employment options emerged as the chief providers of income to the sample households, accounting for slightly more than 50% of the total net incomes of the VLS sample households. The average annual income of the sample households increased by 103% between 1975-78 and 2001-04. The increase was even sharper at 120% in terms of the per capita income. The relative position of the six villages has undergone a major change with Solapur villages surging forward and Akola and Mahabubnagar villages remaining stagnant. The gap between the labor households and landholding households narrowed down and poverty levels were much lower in the labor households when compared to land owning households.

The large variability noted across villages and size groups in household incomes was not visible in consumption expenditures. Consumption expenditures were believed to be determined by customs, habits and permanent income of the households. The surpluses and shortfalls noted in the incomes of households were moderated by savings and borrowings when it came to consumption expenditure. The average consumption expenditure of Rs.26,665 accounted for about 81% of the average household income of Rs.32,818. Overall, 47% of the households suffered energy inadequacy while 53% experienced protein malnutrition. In general, the percentage of households experiencing calorie inadequacy and protein shortfall declined with the increase in the size of holding. The estimates of poverty from macro-level NSSO data for 1999-2000 and VLS data for 2001-04 were compared to see the degree of correspondence between them. It was found that the monthly consumption expenditure per capita increased over the three years period in all the three districts where the VLS villages are located.

The participation rates in the village labor market were higher in Andhra Pradesh villages than in Maharashtra villages, particularly for women. Women in general and those from labor households participated more in the agricultural work while men, particularly from land owning groups participated more in non-agricultural work. The average earnings of women participants varied between one-third and one-half of those of the male labor. Overall, there were adequate opportunities for work both in local and distant labor markets for those who want to participate. On an average, the real wages of male labor increased by 138 % between 1975-78 and 2001-04.

Relatively, the real wages of female labor increased slower than those of male labor. They increased only by 98%. The integration of labor markets has created work opportunities for labor both in farm and non-farm work as well as in local and distant markets. The real wages increased substantially in all the three VLS villages and in the districts where they are located. While the returns to land decreased, those to labor increased substantially. It has significant implication in reducing the inequalities between labor and land-owning households.

Very little investments were made on soil conservation. Most of the investments made were for strengthening the field bunds and leveling of the fields. Very few investments were made for the recommended practices of contour/graded bunding. Relatively, higher investments were made in Maharashtra villages for soil conservation than in Mahabubnagar villages because they received higher support of subsidies. Farmers spent about the same on annual maintenance as they contributed to the soil conservation works. A greater proportion of farmers owning black soils perceived more benefits from soil conservation when compared with those owning red soils. Farmers invested substantially on water exploration, with more emphasis on bore wells in Andhra Pradesh villages and on open dug wells in Maharashtra villages. The average command area per functional water source in VLS villages was 1.8 hectares. The returns to investments on irrigation were around 10% per year in the VLS villages.

Most of the respondents felt that the rainfall has decreased and that the temperatures have increased. But the data do not support these perceptions. The frequency of droughts and the losses associated with them were perceived to be much higher in Andhra Pradesh villages than in Maharashtra villages. The coping mechanisms followed by households include borrowing, drawing from old savings, finding work in non-farm activities, migration etc. The government programs have contributed about eight % of the annual average household incomes. While the programs have intensified over time, the targeting has worsened.

Partners:

ICRISAT  
Oxford University  
Cambridge University  
World Bank  
Yale University  
Cornell University

Publication:

**Rao KPC and Kumara Charyulu D.** 2007. Changes in Agriculture and Village Economies, Research Bulletin no. 21. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

***1.F.2 . Climate change: linking adaptation and mitigation (Asia)***

Opportunities for linking adaptation and mitigation in agriculture and agroforestry

Initial work on the opportunities for linking adaptation and mitigation in agriculture and agroforestry systems were undertaken in collaboration with the World Agroforestry Centre (ICRAF) and other advanced research institutes. The concepts of resilience and sustainable productivity are well established in agriculture and can be linked directly to the discussions about adaptation to and mitigation of climate change. Thus, policy makers can draw upon a substantial body of knowledge on how to enhance the adaptive capacity and mitigation potential of agricultural systems.

If agroforestry is to be used in carbon sequestration schemes such as the Clean Development Mechanism (CDM), better information is required in several areas. For example, we need better data on aboveground and below ground carbon stocks, and the non-CO<sub>2</sub> emissions of different agroforestry systems. Whereas agroforestry systems are primarily production systems, there will be periodic harvesting and marketing of wood products. The debate on durable wood products is ongoing, but provisions will be needed to allow farmers to market wood products from their agroforestry systems and accounting methods will be needed to account for the lifetime of the carbon sequestered in agroforestry products. As small-scale farmers are enrolled in carbon offset projects, we will need to develop a better understanding of the implications for carbon sequestration by agroforestry and what it means to livelihoods. Finally, the CDM has very stringent rules for participation that may be beyond the reach of small-scale farmers to understand or to provide evidence of compliance. There is a need for institutional support by national, regional and international centers of excellence to facilitate an effective participation of small-scale farmers in the CDM.

In an effort to develop adaptation strategies for the agricultural sector, scientists and policymakers must consider the complex interactions of constraints created by changing climates in light of other stress factors. Government and international support in terms of research, education and extension, will be required to help farmers in developing countries cope with the additional stresses created by climate change and increased climate variability.

This earlier work was published in 2005 (Louis VV, Mackensen J, Serigne K, Meine vN, Tomich T, Ong C, Albrecht A, Bantilan C, Anupama KV and Palm C. 2005. Opportunities for linking adaptation and mitigation in agroforestry systems. Pp 103-121. Tropical forests and adaptation to climate change- In search of synergies. Eds. Carmenza Robledo, Markku Kanninen, Lucio Pedroni. Bogor, Indonesia: Centre for International Forestry research).

As cited, the impacts of climate change are being felt on several levels in the agricultural sector: at the level of the individual crop species, at the farming system level (entire farm), and at the level of the natural resource base upon which rural communities depend. Preliminary vulnerability estimates may be too pessimistic for many agricultural systems with high adaptive capacity, but there clearly are limits to adaptation within agriculture. Impacts will be felt most by rural poor in developing countries, who are the most vulnerable because of their low adaptive capacity. The adaptive capacity of farmers in developing countries is severely restricted by heavy reliance on natural factors and lack of complementary inputs and institutional support systems.

A follow-up study applied the concepts to agroforestry. It was featured that agriculture is the human enterprise that is most vulnerable to climate change. Tropical agriculture, particularly subsistence agriculture is particularly vulnerable, as smallholder farmers do not have adequate resources to adapt to climate change. While agroforestry may play a significant role in mitigating the atmospheric accumulation of greenhouse gases (GHG), it also has a role to play in helping smallholder farmers adapt to climate change. In this study, we examine data on the mitigation potential of agroforestry in the humid and sub-humid tropics. We then present the scientific evidence that leads to the expectation that agroforestry also has an important role in climate change adaptation, particularly for smallholder farmers. We conclude with priority research questions that need to be answered concerning the role of agroforestry in both mitigation and adaptation to climate change.

Partners:

World Agroforestry Centre (ICRAF)  
German development bank  
ICRAF-South east Asian Regional office  
Institut de Recherche pour le Developpement (IRD)  
Columbia Earth Institute

Publication:

**Louis VV, Meine V, Serigne K, Tomich T, Ong C, Albrecht A, Mackensen J, Bantilan C, Anupama KV and Palm C.** 2007. Climate change: linking adaptation and mitigation through agroforestry. Mitigation and Adaptation Strategies for Global Change. Pp 18. Springer, Netherlands. ISSN 1381-2386

***1.F.3. Impact of Cooperative Central Banks (CCB) revival package in Andhra Pradesh (Asia)***

Credit is an important bottleneck to the farmers while adopting new technologies. For quite some years, the co-operative credit in India in general and in Andhra Pradesh in particular. The government of India appointed the Vaidyanathan Committee to give recommendations on the reforms needed to revive the co-operative credit in India. It has received loans from World Bank, Asian Development Bank and KZP (Cooperative Fund) and has initiated the process of recapitalizing the District Co-operative Central Banks (DCCBs) in India. The World Bank has entrusted the job of conducting baseline and impact surveys to ICRISAT in three states of India. During 2007, we completed the baseline survey in Vizianagaram, Mahabubnagar and Anantapur districts of Andhra Pradesh. In each of these districts, 24 PACs were selected (7 from those with repayment rates exceeding 50%, 10 from those with repayment rates ranging between 30 and 50% and 7 from those with repayment rates less than 30%) and two villages were randomly selected in case of PACs with a large number of villages under its jurisdiction and one village was randomly selected in case of PACs with a smaller number of villages under its operational area. A total of 36 villages were selected in each of the districts and 10 farmers each of the villages were randomly chosen (5 from regular borrowers, 3 from non-borrowers or those with over dues and 2 from non-members of PACs). Thus, information was collected from a total sample of 1080 households using a

questionnaire developed for the purpose. Similarly, information about the transactions of PACs was collected from the Secretaries of the 72 PACs selected in the three districts. The data entry has been completed and the dataset was sent to the Donors. Some interesting aspects of the data will be analyzed and the baselines for credit levels, incomes, input-output data for important crops, social networks etc will be established in the near future. Similar studies will be undertaken in case of Orissa and Haryana/Gujarat shortly. This three year study offers the scope of learning more about the cooperative credit scenario of the country and the impact of recapitalization package for the DCCBs.

#### ***1.F.4. Partnerships for policy and development strategies with US-universities***

##### Progress on US-universities linkages

The USAID US University-ICRISAT Linkage Initiative was undertaken as an integral part of the ICRISAT agenda and in line with the core research objective of the Yale University Growth center and the International Graduate Programs of the proposed collaborating US based universities. This two-year initiative provided the critical funding support to achieve sustained linkages through village level studies (VLS) among the network of social scientists, natural resource management experts and biological scientists.

This linkage had forged new partnerships and renewed old relationships among the social scientists, researchers and students of US Universities pursuing methodological, developmental, and intergenerational and policy interests using the VLS datasets. ICRISAT VLS has re-engaged with diverse ARI partners from universities and other advanced institutes from UK, USA, Japan, Canada, France and Australia in a longitudinal panel study. This re-engagement commenced in July 2005 with a workshop on “Changes, Livelihoods and Policy” organized by ICRISAT in collaboration with 15 Universities worldwide and in conjunction with the 2005 Annual Meeting of the American Agricultural Economics Association in Providence, Rhode Island, USA. The workshop renewed and strengthened partnerships through the development of an integrated VLS longitudinal panel for assessing long-term changes in village-level economies. The VLS panel data is expected to make a unique path-breaking contribution to the understanding of the dynamics of poverty in rural village economies. The participants of the workshop recommended that production of VLS type datasets become a system-wide priority of Consultative Group for International Agricultural Research (CGIAR).

A multiplier effect has also been created through the development of a proposal to undertake a similar linkage program of ICRISAT with other universities. Several concept notes were subsequently written by other university partners, such as University of Guelph in Canada, to undertake further collaboration in the VLS, particularly one which encouraged a new linkage program amongst other Canadian university partners. Contact was established between ICRISAT/Malawi and the University of Pennsylvania Malawian project (MDICP) that has been collecting longitudinal data since 1998 on 1500 rural women and their families and the role of social networks in how they are learning about and coping with HIV/AIDS. Cambridge University established collaboration for social networks and safety nets-village-level perspectives. To study the insights of village level studies ICRISAT had established a joint collaboration with Cornell University. Oxford University made additional partnership with ICRISAT in the implementation of second generation VLS focusing on poverty dynamics. Discussions are underway between Japan and ICRISAT for the development of the idea notes into pre-proposals for submissions. ICRISAT jointly with the World Bank had undertaken a project on rainfall insurance helping dryland farmers through this linkage program.

Additional funding from potential sources to support the long-term sustainability of collaborations leveraged through this linkage program. Project proposals to various potential partners, organizations and donors and concept notes for CGIAR Challenge Program (CP) were undertaken. Project concept note on ‘climate change and rural household strategies to adapt to them in the semi-arid tropics’ was developed jointly with Central Research Institute for Dryland Agriculture (CRIDA). Project proposal submitted against the call issued by Collective Action and Property Rights (CAPRI). Project proposal were also developed on ‘rural livelihoods, distress and risk behavior’, ‘development pathways in village India’, and “Stimulating Market-led Agricultural and Rural Transformation (SMART)” aligning with CGIAR system-wide priorities. SMART directly address the CGIAR system priorities 5b and 5d emphasizing the criticality of basic research on high-quality longitudinal data in which the CGIAR has comparative advantage. SMART concept note was submitted to Science Council against their call for CP. The Science Council (SC) assessed 41 CP concept notes in the 2nd cycle of selection of CPs. An ICRISAT-IFPRI initiative, the SMART concept note is one among the five that qualified for pre-proposal development. SMART CP is under pre-proposal development for the SC of CGIAR.



Strengthening partnership with the US Universities stimulated interest among researchers and analysts from universities including students to develop new research proposals for undertaking VLS based studies. Research internships (direct and indirect funding) were processed for study visits to gain first hand field experience in the semi-arid tropics (SAT) villages of India. As part of the study, methodology was developed; information was gathered on the selected study villages for village level immersion; surveyed households for primary data; analyzed data; presented major findings at Institute seminar; and documented results and lessons learnt. Presently the works undertaken through these internships are under processes for publication.

Contact was established between ICRISAT/Malawi and the University of Pennsylvania Malawian project (MDICP) that has been collecting longitudinal data since 1998 on 1500 rural women and their families and the role of social networks in how they are learning about and coping with HIV/AIDS. Preliminary explorations indicate that this probable new partnership will have substantial mutual advantages, permitting ICRISAT/Malawi access to considerable longitudinal data related to their interests in HIV/AIDS and agriculture and nutrition and allowing expansion of the MDICP to include more nutritional and agricultural information.

A seminar was organized at the World Bank office in Delhi in March 2007 with a presentation on VLS results and drawing up future plans. About 30 persons from different academic institutions, international agencies and World Bank attended the seminar. The participants discussion centered on the sample design, open access to information and econometric estimates. This seminar encouraged the participants for joint collaborations in proposal development exercise focusing on the analytics of VLS.

The duration of the project is for two years ending May 2007. However, Yale University had requested a no cost extension of the project for one more year ending May 2008. This extension would allow PI and his team at Yale University to schedule travel of the US based researchers to visit ICRISAT as previously agreed upon.

#### Collaborating Institutions and Scientists:

|                                    |                                                                     |
|------------------------------------|---------------------------------------------------------------------|
| Brown University                   | : Andrew Foster                                                     |
| University of Pennsylvania         | : Jere Behrman                                                      |
| Harvard University                 | : Mark Rosenzweig                                                   |
| University of California, Berkeley | : Alain Janvry and Ethan Ligon                                      |
| Purdue University                  | : Wallace Tyner                                                     |
| Yale University                    | : Robert E. Evenson, Chris Udry                                     |
| Oxford University                  | : Stefan Dercon                                                     |
| University of San Francisco        | : Emily Leon                                                        |
| Cornell University                 | : Annemie Maertens, Chris Barret                                    |
| The World Bank                     | : Xavier Gine, Valerie Kozel                                        |
| ICRISAT                            | : MCS Bantilan, KPC Rao, J Ndjeunga, B Shiferaw,<br>P Parthasarathy |

#### ***1.F.5. Temporary and permanent migration in six villages in the semi-arid tropics***

This study has examined changes in the magnitude and duration of migration in the six Indian ICRISAT villages between 1975 and 2005. Migration has been split into two components: temporary migration, which consists of short-term periods of work, related migration and permanent migration consisting of individuals who are no longer considered residents of the villages. At the outset of the VLS, permanent migration predominantly consisted of migrants for marital purposes. The stream of individuals and households permanently leaving the villages for work purposes has increased considerably since this stage, from just under 3 work related migrants per year between 1975 and 1980 to 10 between 1995 and 2005.

Temporary migration flows have also changed considerably since surveying began. At the outset of the survey in 1975, the rates of temporary migration within the villages were viewed as minimal enough to not be of concern. By 1992 the proportion of households conducting temporary migration reported in some villages was over 40%; the data collected in the village since 2002 support the view that temporary migration has become a substantial source of income for some households. Temporary migrants are almost exclusively male and have higher levels of education at the time of undertaking migration. Whilst at the time of migration in 1992 there were insubstantial income and asset differences between households who had a temporary migrant and those who did not, by 2002 the income and non-productive asset differences between the two groups are substantial: the income and assets per capita of households who temporarily migrated are respectively 30% and 50% higher than those who did not. The substantial differentials in growth between the two groups raises interesting

questions about the cause and consequences of temporary migrants, notably whether it is the process of engaging in temporary migration, which allows households to gain a higher level of income or whether the households who choose to engaged in this income generating activity are different, for example in their motivation or ambition, from those who don't. Households that engage in temporary migration in 1992 have substantially higher rates of temporary migration and permanent migration by 2005 than those who do not, suggesting that temporary migration may be something more than a short-term income generating phenomena.

Collaborating Institutions and Scientists:

Yale University : Reena Badiani  
Oxford University : Stefan Dercon  
ICRISAT : KPC Rao, MCS Bantilan

***1.F.6. Forests and common property resources in India: Aurepalle case study***

In the face of rapid industrialization, endemic poverty and population pressure, India faces a balancing act between economic development and environmental conservation, goals that are rarely compatible in the short run. The government of India has a goal of reaching 33% forest cover by 2012.

Aurepalle is a rural village in the Mahabubnagar District of Andhra Pradesh, about 70 km south of Hyderabad, it is within India's semi-arid tropical region and like much of this region, rainfed agriculture is the primary source of income. Livelihood, therefore, is extremely vulnerable to variability in the annual monsoon. In many ways the green revolution bypassed this climatic region. New varieties of high yielding crops could not necessarily be cultivated so extensive agriculture was needed to support growth. As land became increasingly scarce more marginal land was cultivated. Today, no forest cover can be found in Aurepalle. Discussions with locals reveal that much of the land at the base of the hills was once forest area that provided many important common property resources to the local people.

In Aurepalle, privatization and land reform provided incentives to irrigate and cultivate any fertile land; this increased output and income and improved food security over the last 30 years. Landless labor was once heavily dependent on common land, now they are land owners themselves or have left the village. While common land is no longer a productive available resource, there are new opportunities and welfare has improved as the commons have disappeared.

The story in Aurepalle initially appears to be a win for poverty alleviation and loss for the environment. Extensive and intensive agriculture have grown, and increased food security and incomes. However, extensive agriculture appears to have reached its limit, as only the most marginal and unproductive land remains uncultivated. Today, the locals do not complain about the loss of common land because they are now almost all land owners. They complain about a labor shortage.

Has privatization benefited Aurepalle's most marginal groups by making them land owners? The change that has occurred in this village appears to have increased equality. But simultaneous changes in the economic situation may mask the truth. If privatization was inequitable, those who did not benefit may have chosen to leave in search of better opportunity. Further analysis of data collected in Aurepalle will shed light on the relationship between rural poverty and environmental degradation. The relationship has drastically changed in recent years as extensive agriculture reaches its limit and market forces bring new opportunities.

Collaborating Institutions and Scientists:

San Francisco University : Emily Leon  
ICRISAT : KPC Rao, MCS Bantilan

Publication:

**Leon E and Bantilan MCS.** Under review. Forests and common property resources in India: Aurepalle case study. Draft paper. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

***1.F.7. Livelihood insecurities in SAT: Migration, risk behavior and impact of HIV on rural households in Andhra Pradesh (Asia)***

This thesis looks at issues related to livelihood insecurities in the semi arid tropics (SAT); the risks and vulnerabilities that hinder the growth process of households, with particular reference to sexual risk behavior and HIV linkages of migrant workers. A livelihood comprises of the capabilities, assets and activities required for people's means of living. In conditions of drought, migration is a major alternative livelihood strategy in the marginal semi-arid environments of rural India. Recent reports by National AIDS Control Organization's sentinel surveillance indicate that the semi-arid tropics fall under high prevalent zones in terms of HIV. It also lists migrant workers as a high-risk group prone to the disease. Livelihoods can be destroyed by the impact of HIV/AIDS when economically active people succumb to the disease and die. Consequently, children drop out of school to cultivate the land and care for ill parents. This hampers the children's ability to acquire skills that could make them employable in the formal sector. To pay for medicines, hospital care or other expenses due to HIV/AIDS, a family may sell stocks of food, land or other property, farming tools, or send their sons and daughters to the city to find work. This again leads to labor migration and hence leads to risk of infection again. These impacts of the poverty-livelihood-HIV nexus are clearly documented in studies in Africa. However, in India though there are sparse micro level information, an in-depth analysis is yet to begin. Given the fact that HIV has high prevalence in the SAT and is increasing constantly, this study aims at understanding the role of migration in the spread of the HIV epidemic in the rural SAT and aims to understand the socioeconomic conditions of the rural households involved in this process of migration. This kind of information is aimed at enabling policy makers to make informed decisions when it comes to planning for rural development or disease control for that matter.

The broad objective of this thesis is to understand the role of migration in enhancing the risk behavior of migrants and in the spread of the HIV epidemic among rural households in the SAT. The specific objectives are to understand 1) to what extent the livelihood insecurities in Dokur lead to migration, 2) to understand the risk behavior of migrant workers in the context of livelihood insecurities and 3) to map and analyze the patterns of migration and risk behavior.

The area of study planned is from the high prevalence state of Andhra Pradesh. Samples will be chosen from Dokur village in the heart of the rural SAT with high incidence of migration. Secondary data from the Voluntary Counseling and Testing Centre will also be analyzed to gain more insight.

Collaborating institutions and scientists:

Indian Institute of Technology, Bombay : D Parthasarathy, R Robinson, K Narayanan  
ICRISAT : BVJ Gandhi, MCS Bantilan

Publications:

**Gandhi BVJ, Bantilan MCS and Parthasarathy D.** 2007. Livelihood risk to HIV risk in the semi arid tropics of rural Andhra Pradesh. Paper presented at the UNU – WIDER Conference on Fragile states and fragile groups, June 15–16, 2007, Helsinki, Finland. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

**Gandhi BVJ, Bantilan MCS and Parthasarathy D.** Forthcoming. Livelihood risk to HIV risk in the semi arid tropics of rural Andhra Pradesh: Book chapter *in* Fragile states and fragile Groups in the global economy: How to tackle economic and social vulnerability. United Nations University, World Institute for Development Economics Research (UNU-WIDER) Publications.

***1.F.8. The potential contribution of agricultural technologies to reducing vulnerability to HIV among women smallholder farmers in Malawi (ESA)***

Rationale: Conventional AIDS interventions aimed at raising awareness remain barely effective in sub-Saharan Africa, arguably because structural underlying causes of the pandemic inhibit people, especially poor women, to live up to the propagated behavior changes. A different approach is urgently needed, one that does address those underlying causes. While much scientific attention goes to identifying and mitigating the devastating impacts of AIDS, little attention is directed at understanding and addressing the drivers of the pandemic. This research project aims to increase understanding of the facilitators of the pandemic, especially food insecurity and gender inequality, and to identify ways of addressing these through appropriate agricultural interventions.

Main objective: To increase understanding on the impact of livelihood insecurity of rural women in Malawi on their susceptibility to HIV, current ineffectiveness of interventions aiming to change agricultural and sexual behavior, and opportunities to increase the impact of such interventions in order to mitigate the spread of HIV.

Key results and implications for future: In a practical sense, this research project aims to formulate recommendations to policy makers and project planners, agricultural research institutions and extension services on how to realize the potential contribution of agricultural development to reducing vulnerability to HIV infection among women smallholder farmers in Malawi. Through improved understanding of the needs, constraints, priorities and information flow pathways of differently situated women smallholder farmers, recommendations will be made on how to increase the relevance of innovations and effectiveness of extension methods for these various types of women. By using such a livelihood perspective, the research aims to broaden the scope of HIV prevention efforts and so increase their effectiveness. By using a qualitative lens to look at issues that are generally assessed with quantitative research tools, it is aimed for that recommendations can also be made to increase the effectiveness of future quantitative research instruments.

On a more academic level, this research project aims to increase theoretic understanding of the practice of development intervening through the transfer of modern information; increase understanding of the factors that contribute to HIV vulnerability; and increase theoretical understanding of how anthropological research can contribute to solving practical problems.

Methodology used: Extensive literature review accomplished. Since October 2007 (until end 2008) data collection through participant observation, formal and informal interviews (later also quantitative surveys).

Milestones and achievements: Extensive literature review on paper, which has resulted in 2 publications based on findings. As per February accepted PhD student on this topic at the University of Amsterdam, so assured extra time and funding for study. Selected study sites and received permission from officials concerned. Learned to communicate in local language. Developed and pre-tested research instrument (interview questions/topic list).

Major findings: Findings result only from literature review, as empirical data collection has only just begun: Women are disproportionately infected, already constituting 59% of all infected in SSA. Furthermore, while infection rates are still highest in the urban areas, rates increase fastest in the rural areas, where the total number of infected now outnumbers the total urban infected. Within the field of agriculture and AIDS, by far most attention is directed at identifying and mitigating the devastating impacts of AIDS on food security. Far less attention has been directed at the reverse relationship: how food insecurity fuels the pandemic. This fueling is both through weakened, malnourished and thus more susceptible bodies, as well as pushing the hungry to survival strategies such as male migration and female transactional sex that increase risk of HIV spreading. More understanding is urgently needed of the mechanisms that put (especially rural) women at risk of infection, and ways through which the resistance of poor women farmers can be increased.

Partners:

University of Amsterdam

IS-Academy (The IS-Academy is a collaboration between the Dutch Ministry of Foreign Affairs and various Dutch universities)

Amsterdam School of Social Science Research

Dutch Ministry of Foreign Affairs

Publications:

**Verheijen J.** In press. Gender-sensitive agricultural interventions as tool for mitigating HIV and AIDS. *Journal of Medical Anthropology* 19 (2).

**Verheijen J** and **Minde IJ.** Forthcoming. Agricultural innovations: A potential tool to HIV mitigation. *Journal of SAT Agricultural Research*. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

***1.F.9. Managing risk in agriculture in semi-arid tropics (SAT) of Andhra Pradesh***

The study was undertaken to find out various facets of risk confronting three predominantly rainfed districts of Andhra Pradesh viz., Prakasam in Coastal Andhra, Anantapur in Rayalaseema and Mahabubnagar in Telengana regions. Various secondary data sources as well as primary data collected from 240 households from 12 villages of six mandals in the three districts were used to achieve the following objectives:

- To characterize the nature and magnitude of risk in the semi-arid tropics

- To assess the attitudes of the farmers towards risk in the three rainfed districts of the state
- To study the trends in diversification of crop and livestock enterprises
- To evolve risk efficient farm plans to farmers of diverse resource endowments
- To assess the crop insurance and weather insurance programs to cover risks and suggest an appropriate mix of insurance schemes

In order to quantify risks, distributions of crop areas, crop yields, farm harvest prices (deflated) and gross returns (deflated) were computed and different measures of risk such as coefficient of variation, instability index and average negative deviations from mean were calculated. Risk attitudes of the sample farmers were studied based on the options chosen by them among the six alternatives representing different expected values and variability in returns. The risk aversion coefficients were regressed on the demographic and socio economic variables to assess whether risk attitude is a personal trait or influenced by any of the explanatory variables. Since diversification is touted as an important risk reduction strategy, diversification indices were computed for both crop and livestock enterprises in the districts based on secondary data. Regressions were run for the entire period to study the effect of different explanatory variables on diversification. The existing farm plans of different size groups of sample households were improved by using both linear and MOTAD programming techniques with the same enterprises, resource levels and input-output coefficients. Since insurance is emerging as an important policy initiative to reduce the variability in the incomes of the farmers, the performance of the National Agricultural Insurance Scheme (NAIS) and rainfall insurance were studied and compared.

The results revealed that very often the distributions deviated from normality, particularly in case of real farm harvest prices and real gross incomes. The newly introduced crops like maize and sunflower in the study districts generally showed high coefficients of variations. The instability index gave similar results as the coefficient of variation. Among different crops, the average negative deviations were higher for mango and commercial crops. The distributions of risk aversion coefficients of the sample farmers in the study districts showed a higher risk aversion in 2004 when compared with that in 2006. The regression results indicated that the richer households had lower risk aversion coefficients. The households with larger family sizes also displayed more risk aversion than those with smaller sized households. The diversification results indicated an increasing diversification of crop enterprises in Prakasam and Mahabubnagar districts, while Anantapur district followed a path of specialization in groundnut cultivation. In the districts where diversification increased, variability in crop yields, farm harvest prices and gross returns decreased, indicating a reduction in risk. Regressions with secondary data for the period 1969-2005 have shown that the drivers of diversification were different in the three study districts. Specialization increased in favor of sheep in all the three study districts. In general, increase in human population favored livestock diversification while time trend and gross cropped area favored specialization in livestock. The linear and MOTAD programming exercises helped in developing alternate plans with higher incomes and lower risks even with the same level of resources and technology. Except in the case of smallholder farmers in Prakasam district, it was possible either to increase incomes or to reduce risks or both in all other eight synthetic (average) farm situations. The insurance results showed that relative to rainfall insurance schemes, farmers got much higher benefits from crop loan insurance schemes.

Strengthening the access to institutional credit in the study area and promoting the rainfall insurance by building subsidies into it to cover the farmers who don't have access to institutional credit are some of the policy implications suggested.

Collaborating Institutions and Scientists:

Acharya N.G Ranga Agricultural University : D Kumara Charyulu, Dr VT Raju  
ICRISAT : KPC Rao

Publication:

**Kumara Charyulu D and Raju VT.** 2007. Managing risk in agriculture in semi-arid tropics (SAT) of Andhra Pradesh. Thesis submitted to Acharya N.G.Ranga Agricultural University, Andhra Pradesh, India.

***1.F.10. Development pathways and sustainable agriculture***

Technologies need to be designed and deployed with a context in mind, and in consultation with prospective users to meet their needs. It is important and useful to consider how it would enable and motivate the poor to move along 'development pathways' that lead to increasing prosperity, food security, equity and sustainability. As human populations increase, a number of different development pathways could unfold. People might fight over increasingly scarce natural resources and not replace those that are removed, spiraling downward into ever-

greater poverty. Or, they could invest in their lands, increasing their production efficiency, incomes and total output, meeting the needs of ever-larger populations. Research-for-development institutions have key roles to play in the march along dryland development pathways and to better assist them in this planning by adopting a development pathways perspective. ICRISAT's research-for-development community plays a major role in steering development towards the second type of pathway. Such pathways need to have the following characteristics: (a) enhance the natural resource base; (b) consider the circumstances; (c) increase incomes; connect to markets; (d) manage risks; (e) diversify; (f) innovate; (g) customize and adapt; and (h) steady and sustained. Without addressing these issues, sustained productivity gains are unlikely. So it is necessary that a development pathways perspective considers how prospective steps along the path would be influenced by these elements, and obstacles ahead be cleared to reach the desired destination of sustainable prosperity and security.

Publication:

**ICRISAT (International Crops Research Institute for the Semi-Arid Tropics).** 2007. Dryland development pathways. What ICRISAT Thinks. Patancheru, Andhra Pradesh: ICRISAT. 4 pp.

*1.F.11. Poverty dynamics and development pathways (WCA)*

As part of revival of village level studies, a three-year database was collected from 6 villages of western Niger namely Sadeizi Koira, Samari, Gobery, Fabidji, Faska and Hankoura. These villages are located in different agro-ecologies with Sadeizi Koira and Samari located in the area of about 400 mm rainfall on average; Gobery and Fabidji in the region of about 600 mm rainfall and Faska and Hankoura in the region of 800 mm. The data was collected from 2003/04 to 2005/06 and includes 15 modules as follows:

- Module 0. General information and questionnaire identification
- Module 1. Characteristics of production units
- Module 2. Production unit land stocks
- Module 3. Migration
- Module 4. Agricultural equipment
- Module 5. Use of technologies
- Module 6. Labor use
- Module 7. Credit transactions
- Module 8. Diversification of revenues
- Module 9. Crops: Flux and stocks
- Module 10. Livestock: Flux and stocks
- Module 11. Affiliation to associations, institutions and rural development projects
- Module 12. Wealth indicators
- Module 13. Risk coping mechanisms and responses
- Module 14. Health risks of household members

The data documentation is completed. Preliminary analysis is on-going and is being used to develop a proposal for mobilizing resources for VLS studies in WCA.

## List of Publications in 2007

### Journal Articles:

**Ashok S Alur, Parthasarathy Rao P, Ravinder Reddy Ch, Gowda CLL, Reddy BVS and Rai K N.** 2007. Making markets work for the poor. <http://www.commodityindia.com>; Vol. 7, (1): 11-14

**Gurava Reddy K, Parthasarathy Rao P, Bellum VS Reddy, Rajashekhar Reddy A, Rao CLN, Chengal Reddy P and Janardhan Rao Ch.** 2007. Enhancing technology generation and transfer through coalition approach: A case of sorghum poultry coalition, Andhra Pradesh, India. *International Journal of Technology Management and Sustainable Development*: 5(2). Bristol, UK.

**Nkonya E, Shiferaw B and Msangi S.** 2007. Food security in the drylands of South Asia and Sub-Saharan Africa: Research challenges and opportunities. *Annals of Arid Zone* (Invited journal article for a special issue on Alternate Land use Systems)

**Parthasarathy Rao P, Gurava Reddy K, Reddy BVS and Ramchandriah D.** 2007. Farmers' perceptions on performance and utilization of improved sorghum cultivars. *Manage Extension and Research Review*. Vol: VII(1): 53-62.

**Verheijen J.** 2007. Gender-sensitive agricultural interventions as tool for mitigating HIV and AIDS. *Journal of Medical Anthropology* 19 (2).

### Conference Proceedings:

**Alur, Ashok S, Ravinder Reddy Ch, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Markets access for poverty reduction and improved livelihoods of small and marginal scale dry land farmers: Presented at the International Conference on Ethnographic Discourse of the Other. University of Hyderabad, 3-5, July 2007, Hyderabad, India

**Belum VS Reddy, Ashok Kumar P, Parthasarathy Rao P and Sanjana Reddy P.** 2007. Sweet sorghum domains, hybrid sweet sorghum seed, and agronomic practices: an overview. Paper presented at the Global consultation on pro-poor sweet sorghum development for bioethanol production and Introduction to tropical sugar beet agenda, 8-9 November, 2007, Rome.

**Birthal PS and Parthasarathy Rao P.** 2007. Changing agricultural scenario: Institutional innovations for linking small farmers to markets. Paper presented at the National Seminar on "Agrarian Distress: Causes and Remedies", August 1-2 2007, National Center for Agricultural Economics and Policy Research, New Delhi. NCAP and Indian Society of Agricultural Economics.

**Gandhi BVJ, Bantilan MCS and Parthasarathy D.** 2007. Livelihood risk to HIV risk in the Semi Arid tropics of rural Andhra Pradesh. Paper presented at the UNU – WIDER Conference on Fragile States and Fragile Groups, Helsinki, Finland, 15–16 June 2007.

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**Bantilan MCS and Keatinge JDH.** 2007. Considerations for determining research priorities: Learning cycles, feedback and impact pathways. . Pp 37-64 *in* Agricultural Research Management (Loebentein G and Thottapilly G, eds.). Springer, Netherlands. ISSN

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#### **Bulletins:**

**Rao KPC and Kumara Charyulu D.** 2007. Changes in agriculture and village economies, Research bulletin no. 21. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

#### **Concept notes/Project proposals:**

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**Pender J and Ndjeunga J.** 2007. Assessing impacts of sustainable land management programs on land management and poverty in Niger. Draft Report.

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**Chilonda P, Machette C and Minde JJ.** 2006. Poverty, food security and agricultural growth trends in southern Africa. The Regional Strategic Analysis and Knowledge Support System (Re SAKSS) Discussion Paper No.3 2006. Re SAKSS. Pretoria: South Africa

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#### **Brochures/ Pamphlets:**

**GT-IMPI.** 2007. GT-IMPI Information brochure. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 6 pp.

### **Policy Briefs:**

**Chilonda P and Minde IJ.** 2007. Agricultural growth trends in Southern Africa Policy brief No. 1. The Regional Strategic Analysis and Knowledge Support System, Pretoria: South Africa

**Eastern and Southern Africa Seed Alliance:** Project Brief: ICRISAT; Iowa State University Seed Center and CNFA(Citizens Network for Foreign Affairs), Inc August 2007.

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**Homann S.** 2007. Gain from goats. SATrends no.74. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

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**ICRISAT (International Crops Research Institute for the Semi-Arid Tropics).** 2007. Pigeonpea Technology Adoption and Impact in Kenya and Tanzania. Poster paper prepared for the ICRISAT Governing Board meeting in Lilongwe, Malawi, 22-25 Oct 2007.

### **Electronic modules developed in 2007:**

**Bantilan MCS.**2007. Research Innovation, adoption and impact cycle. Lecture delivered on 6 December 2007, document and PowerPoint presentation to the participants of the ICRISAT-CRIDA training programme on "Farming System Approach for Livelihood Improvement of Rainfed Farmers", held at ICRISAT, Patancheru.(About 30 participants from different Agricultural Research Institutes and Universities across India.)

**Bantilan MCS.**2007. Impact pathway analysis. Lecture delivered during WCA In-House Review, Niger, June 2007.

**GT-IMPI.** 2007. Village-level Studies. Information Portal. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

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#### WIT:

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#### Thesis

**Kumara Charyulu D** and **Raju VT.** 2007. Managing risk in agriculture in semi-arid tropics (SAT) of Andhra Pradesh. Ph.D. Thesis. Rajendranagar 500 030, Andhra Pradesh, India: Acharya N.G.Ranga Agricultural University.

### **Forthcoming Publications**

#### Journal Articles:

**Audi P, Nagarajan L** and **Jones R.** Under review. Seed interventions and cultivar diversity pigeonpea: a farmer based assessment in Eastern Kenya. Paper submitted and under review by Journal of New Seeds

**Bantilan MCS** and **Padmaja R.** Forthcoming. Empowerment through social capital build-up: Gender dimensions through technology uptake. Journal of Experimental Agriculture. 32 Avenue of the Americas, NY 10013-2473, New York, Cambridge University Press

**Mazvimavi K, Twomlow S** and **Minde IJ.** Forthcoming . Intensity of conservation farming adoption in Zimbabwe. Journal article.

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**Shiferaw B, Kebede TA** and **You Z.** Under review. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. Agricultural Economics

**Shiferaw B, Obare G** and **Muricho G.** Under review. Leveraging institutions for collective action to improve markets for smallholder producers in less-favored areas. African Journal of Agricultural and Resource Economics. Pretoria: South Africa.

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**Shiferaw B, Reddy VR** and **Wani S.** Under review. Watershed Externalities, shifting cropping patterns and groundwater depletion in Indian semi-arid villages: The effect of alternative water pricing policies. Ecological Economics. PO Box 44194, West Allis, WI 53214, USA: The International Society for Ecological Economics.

**Twomlow S, Shiferaw B, Cooper P and Keatinge JDH.** Forthcoming. Integrating genetics and natural resource management for technology targeting and greater impact of agricultural research in the semi-arid tropics. Journal of Experimental Agriculture. 32 Avenue of the Americas, NY 10013-2473, New York, Cambridge University Press

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#### **Book Chapters:**

**Gandhi BVJ, Bantilan MCS and Parthasarathy D.** Forthcoming. Livelihood risk to HIV risk in the semi arid tropics of rural Andhra Pradesh: fragile States and fragile groups in the global economy: How to tackle economic and social vulnerability, Book chapter. United Nations University, World Institute for Development Economics Research (UNU-WIDER) Publications.

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**Mazvimavi K and Twomlow S.** Forthcoming. Conservation farming for agricultural relief and development in Zimbabwe. No-Till Farming Systems (Special Publication III of the World Association of Soil and Water Conservation)

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**Shiferaw B, Obare G and Muricho G.** Forthcoming. Rural market imperfections and the role of institutions for collective action to improve markets for the poor. CAPRI book chapter. 2033 K Street, N.W. Washington, D.C., 20006-1002, USA: International Food Policy Research Institute.

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#### **Books and Journal Volumes:**

**Parthasarathy Rao P and Birthal PS.** Forthcoming. Raising livestock productivity in smallholder crop-livestock systems in South Asia. Patancheru 502324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, Pusa, New Delhi, India: National Centre for Agricultural Economics and Policy Research and PO Box 5689, Addis Ababa, Ethiopia: CGIAR Systemwide Livestock Programme.

#### **Progress Reports:**

**Minde IJ, Mazvimavi K, Pedzisa T, Ndlovu P and Musitini T.** Forthcoming . Small packs fertilizer use in Zimbabwe and South Africa. Draft report. PO Box 39063, Nairobi, Kenya: International Crops Research Institute for the Semi-Arid Tropics.

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## **Project 2**

### **Sustaining biodiversity of Sorghum, Pearl Millet, Small Millets, Groundnut, Pigeonpea and Chickpea for current and future generations**

Currently, the ICRISAT genebank holds 118,882 germplasm accessions of its mandate crops and small millets representing 144 countries of the world.

The entire germplasm collection at ICRISAT-Patancheru is conserved in medium-term-storage (MTS) (4°C, 30% RH). These collections will also be conserved in long-term-storage (LTS) (-20°C) in a phased manner. At present about 87% of accessions have already been placed in LTS. The entire germplasm also needs to be conserved in safety-backup in locations outside India. At present, 16% of the germplasm have been placed in safety-backup at the ICRISAT Regional Genebank at Niamey, Niger (groundnut, pearl millet and six small millets) and ICARDA, Syria (chickpea).

Agronomic and botanical characterization is necessary to facilitate the utilization of germplasm. Evaluation of germplasm accessions for traits of agronomic importance enhances its utility for greater use by research workers. Germplasm accessions of all the crops have been sown in batches over the years and characterized for botanical and agronomic traits. Germplasm screening against insect pests and diseases, and abiotic stresses were carried out in collaboration with entomologists, pathologists and physiologists. Grains were tested for nutritive value such as protein and oil content and cooking time.

There has been insufficient use of germplasm in crop improvement programs. This is possibly because of the large size of collections and unavailability of data on traits of breeder's interest, which show large genotype x environment (G x E) interactions and require replicated multi-location evaluations. Developing core collections (10% of the entire collection) representing the species diversity is a means to reduce the size for meaningful evaluation. At ICRISAT, we have studied the diversity of germplasm collections using the available characterization and evaluation and passport data, and developed core collections of all the five mandate crops and finger millet (2247 accessions of sorghum, 2094 of pearl millet, 1956 of chickpea, 1290 of pigeonpea, 1704 of groundnut, 622 of finger millet and 155 foxtail millet). However, when the size of entire collection is large, even a core collection size becomes unwieldy for evaluation by breeders. To tackle this challenge further, ICRISAT scientists developed a two-stage strategy to develop a mini-core collection, which consists of 10% of the core collection (only 1% of the entire collection). This mini-core subset still represents most of the diversity of the entire core collection. The first stage involves developing a representative core subset (about 10%) from the entire collection using all the available information on origin, geographical distribution, and characterization and evaluation data of accessions. The second stage involves evaluation of the core subset for various morphological, agronomic, and quality traits, and selecting a further subset of about 10% accessions from the core subset. At both stages standard clustering procedure is used to separate groups of similar accessions. At ICRISAT, we have already developed mini-core collections of chickpea (211 accessions), groundnut (184 accessions), pigeonpea (146 accessions), sorghum (242 accessions) and finger millet (65 accessions).

Development of a 'composite set' of germplasm in research has been conceptualized in recent years due to the initiative of the Generation Challenge Program. The composite set representing the entire collection by geographic origin, mini-core sets, main germplasm diversities, and other economic traits have been established at ICRISAT for sorghum and chickpea (3000 accessions each), groundnut, pigeonpea, pearl millet and finger millet (1000 accessions each) and foxtail millet (500 accessions). The composite sets have been genotyped using 20-50 SSR markers molecular markers to assess the molecular diversity in the composite collection and devise the strategies for exploiting it for crop improvement, especially for traits such as drought tolerance and other economic traits. Such approaches will enhance breeders' efficiency in utilizing allelic diversity existing in genebank material (genetically diverse germplasm) in practical breeding programs. The results on genotyping of the composite collection of chickpea and sorghum with 50 SSR markers, and groundnut and pigeonpea with 20 SSR markers are being analyzed at present at ICRISAT to determine the population structure and for defining a reference set of 300 most diverse genotypes. These 300 genotypes will be used for extensive phenotyping and genotyping with additional markers to undertake association mapping studies for identifying markers associated with traits related to drought tolerance and other agronomic traits.

Besides germplasm of sorghum, pearl millet, chickpea, pigeonpea, and groundnut (staple crops), ICRISAT also conserves, characterizes, and promotes the utilization of six small millets (finger-, foxtail-, barnyard-, kodo-, little-, and proso-millet) that have regional and location-specific importance and as such classified as under-

utilized crops. ICRISAT genebank holds 10,193 accessions (5,949 finger millet, 1535 foxtail millet, 842 proso millet, 743 barnyard millet, 658 kodo millet, and 466 little millet) of these crops. The entire small millets collection is conserved in medium-term-storage (MTS) (4°C, 30% RH), and will also be conserved in long-term storage (LTS) (-20°C) in a phased manner. By 2007, 7751 accessions (76% of the germplasm) have been placed in LTS. The entire germplasm of the under-utilized crops collection will need to be conserved as safety-backup in location(s) outside India. By 2007, 4580 (finger millet), 1039 (foxtail millet), 521 (proso millet), 375 (little millet), 628 (kodo millet) and 479 (barnyard millet) accessions have been placed in safety-backup at ICRISAT Regional Genebank at Niamey, Niger.

## **Output A: Germplasm of staple crops assembled and conserved and germplasm characterized and documented for utilization and knowledge shared with partners**

### **Summary**

*During 2007, the passport databases of our mandate crop collections were compared with those of collections at ARS - Griffin, USA for groundnut and IER, Mali and ICRISAT-Niamey for pearl millet and a total of 958 accessions identified as unique that are not available in the ICRISAT genebank. Our efforts to introduce the unique germplasm resulted in the introduction of 21 accessions of sorghum from USDA, USA, 423 pearl millet collections from Niger and 72 accessions of chickpea from Ukraine. We also secured import permits for pigeonpea (231 accessions) collected in Tanzania, Uganda and Mozambique. We have made formal requests for securing unique germplasm of sorghum and groundnut from CAAS, China.*

*Morpho-agronomic characterization of new germplasm was undertaken to enhance germplasm utilization. We characterized under post-rainy season conditions 482 new accessions of sorghum collected and 747 accessions of chickpea assembled from USA. A total of 3039 accessions consisting 242 accessions of sorghum, 468 chickpea, 106 pigeonpea and 2223 groundnut were characterized to fill the gaps in characterization databases.*

*We evaluated 1297 accessions of sorghum and identified 24 collected from Niger as promising for sweet stalk. In chickpea, we evaluated sets of germplasm including early maturity (17), large-seeded Kabuli (116), salinity tolerant (52), drought tolerant (20), agronomic traits (1678) and reference set for seed yield (300). Several agronomically superior germplasm lines were identified in each set. The groundnut reference set (300) and large seeded accessions (25) were evaluated for agronomic traits. In pigeonpea, vegetable type (105) and salinity tolerant (29) accessions were planted for evaluation. Chickpea reference set revealed considerable variation for resistance/susceptibility to pod borer, *Helicoverpa armigera*. In chickpea, resistance to ascochyta blight, botrytis gray mold, collar rot, dry root rot and, fusarium wilt was confirmed in several accessions.*

*Agronomic evaluation of 29 pigeonpea landraces from Uganda revealed differential adaptation to cooler and warmer temperatures. Delayed phenology at the cool site at Kabete indicates that the Uganda accessions have high optimum temperature and would form a basis for breeding for climate change where mean temperatures are expected to increase.*

*At Patancheru, we secured adequate seed quantities from 5700 accessions regenerated during 2006 and planted 6426 accessions of different crops to replenish seed stocks this year. Seed viability of 8116 accessions of staple crops germplasm was tested, including viability of 1647 accessions conserved as active and 3416 as base collection. Germplasm with seed viability above 85% were processed as base collection. The mean seed viability of base collection ranged from 95.9% for sorghum to 93.5% for pearl millet. Systematic seed health testing was done for a total of 1784 accessions of staple crops germplasm. We processed a total of 6388 freshly harvested germplasm samples as active collection (3773) and base collection (2615) and with these additions the base collection increased to 103,818 accessions (87.3%). The genebank at Sadore, Niger tested seed viability of 2877 accessions of staple crops and regenerated 1792 accessions for conservation.*

*Influence of seed size in chickpea during drying and moisture content and storage conditions in groundnut on longevity were studied and were identified factors contributing to cost-effective protocols.*

*Germplasm databases on passport information (3505 accessions), characterization (6108) and seed supply were updated for uploading to the SINGER database.*



We supplied 1886 samples of staple crops (chickpea 944, groundnut 117, pearl millet 34, pigeonpea 270 and sorghum 521) for utilization to scientists in 16 countries using the SMTA/MTA. Additionally, 6669 samples were supplied for utilization within the institute.

#### **MTP output targets – 2007**

##### ***Output target 2.1.1: Global databases of chickpea and pigeonpea compared to identify unique germplasm***

Germplasm databases of chickpea at ICRISAT and the National Centre for Plant Genetic Resources of Ukraine (NCPGRU) were compared and 313 accessions identified as being unique for inclusion in our collection. We have secured 72 accessions for planting and further release by NBPGR. We continue our efforts in getting the remaining germplasm from Ukraine. Similarly, we also compared our chickpea database with collections at ICARDA, Syria and USDA, USA for identifying unique material especially wild *Cicer* for inclusion in our collection. Strengthening the pigeonpea germplasm database at ICRISAT was emphasized during the Global Germplasm Conservation Strategies meetings in 2006. The pigeonpea germplasm database of ICRISAT were compared with the ICRISAT collection at Nairobi and the National Dryland Farming Research Station (NDFRS), Kenya, the Australian Tropical Crops Genetic Resource Centre, Australia and with national collections in India at the Indian Institute of Pulses Research, Kanpur and Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Sehore to identify unique germplasm for assembly at Patancheru. These efforts have resulted in identifying several germplasm accessions especially for filling gaps in traits like plant type and maturity in both crops.

##### ***Output target 2.1.2: Chickpea germplasm from ICARDA (500 accessions) and 600 groundnut germplasm from Japan assembled and characterized***

We characterized 417 accessions assembled from ICARDA in the field during the 2006-07 post-rainy season and regenerated 14 accessions with limited seed quantities for seed multiplication in the glasshouse. The characterized set represents 384 kabuli type, 26 desi type and seven intermediate type accessions. The characterization traits included days to 50% flowering, days to flower ending, flowering duration, flower color, plant color, plant height, plant width, growth habit, days to maturity, number of basal primary branches, number of apical primary branches, number of basal secondary branches, number of apical secondary branches, number of tertiary branches, seed color, seed shape, seed texture, dots on seed color, pods per plant, 100-seed weight and yield per plant. This has resulted in identifying several promising sources for further testing and utilization. These include, 12 accessions with 100-seed weight >50 g, five accessions with high yield potential (2.73 to 2.85 t ha<sup>-1</sup>) and other five accessions having combination of large seed size (100-seed size >40g) and high yield potential (2.14 to 2.82 t ha<sup>-1</sup>). We regenerated, 47 groundnut germplasm samples (disease free seeds) received from National Institute of Agro-biological Sciences (NIAS) Japan for further characterization. The remaining accessions (400 groundnut accessions) have also been released by the NBPGR for observation, seed increase and detailed characterization for morphological and agronomic traits.

##### ***Output target 2.2.1: Global databases of finger millet compared to identify unique germplasm and to determine gaps in future collection***

The finger millet germplasm databases of national collection in Kenya and ICRISAT (Niamey) were compared with ICRISAT, Patancheru to identify unique germplasm. We corresponded with the Tamil Nadu Agricultural University (TNAU), Coimbatore, on the subject of their recently collected finger millet germplasm accessions. We secured from them seven samples collected in Tamil Nadu, India for conservation and utilization. We have identified some of the national collections in India, Kenya, Tanzania and Uganda as unique for comparison of databases for identifying unique accessions for filling gaps in the ICRISAT collection. Contacts with some of the NARS in these countries eg, University of Agricultural Sciences, Bangalore, Acharya N G Ranga Agricultural University, Hyderabad and Rajendra Agricultural University, Muzaffarpur in India, the National Agricultural Research Organization, Uganda, Kenya Agricultural Research Institute, Kenya and Department of Research and Development, Tanzania were established for identifying unique germplasm for future assembly and filling the gaps in our collection.

**Output target 2.2.2: Priority areas identified with associated capacity development for finger millet collection/assembly in collaboration with NARS**

Finger millet is an important crop in several countries of Asia and East Africa. The germplasm collection at ICRISAT represents 5949 accessions from 24 countries. However, gaps exist in the collection for some important morpho-agronomic traits especially extra-early and very late-maturing types, tall types for fodder use and most desirable white grain types. The races representing *elongata* and *compacta* (cultivated) and race *Africana* and *spontanea* (wild types) are poorly represented in the collection. Also, some of the geographical regions were not covered or poorly represented in the existing collection. Priority areas identified for collection include Burundi, Ethiopia (centre of origin), India, Kenya, Malawi, Nepal, Rwanda, southern Sudan, Tanzania, Uganda, Zaire and Zambia. We have identified NARS in some of the countries in Asia, India, and countries in East Africa (Kenya, Tanzania and Uganda) for enhancing this activity.

**Output target 2.3.1: Composite sets of germplasm established for utilization**

**Composite collections developed and phenotypic diversity studied**

**Groundnut:** A composite collection of groundnut consisting of 1000 accessions was developed in collaboration with Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil. The composite collection includes accessions from ICRISAT groundnut mini core collection (184), mini core comparator (184), Asia mini core (50), high yield combined with large seed size and high shelling percentage from Asia core (60), released cultivars (36), biotic stresses resistant (104), abiotic stresses resistant (40), fresh seed dormancy (6), early maturity (25), large seed size (16), high shelling percentage (10), high oil content (9), high protein content (9), interspecific derivatives (5), earlier genotyped (18), and 52 accessions of 14 wild *Arachis* species. The composite includes accessions from EMBRAPA for diverse origin and botanical varieties (130) and wild relatives (62) (Table 1). The composite collection includes 181 advanced lines, 245 breeding lines, 460 landraces, and 114 accessions of *Arachis* wild relatives. Region wise, Asia contributed maximum (44.5%) to the composite collections, followed by The Americas (31.2%), and Africa (18.4%). Europe and Oceania contributed less than 1% to the composite collection. The composite collection was phenotyped for 15 morphological and 16 agronomic characteristics in the rainy and post-rainy seasons at ICRISAT Patancheru. The composite collection was also phenotyped for the traits related to drought like SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA) at 60 and 80 days after sowing in the rainy season. Large range of variation was observed for traits related to pod yield and drought (Table 2).

**Table 1. Composite collection of groundnut.**

| Character                                      | Accessions number | Character                                                         | Accessions number |
|------------------------------------------------|-------------------|-------------------------------------------------------------------|-------------------|
| <b>ICRISAT</b>                                 |                   |                                                                   |                   |
| Mini core                                      | 184               | Early maturing                                                    | 25                |
| Mini core comparator                           | 184               | Large seeded                                                      | 16                |
| Asia mini core                                 | 50                | High Shelling percentage                                          | 10                |
| Best accessions from Asia core                 | 60                | High oil content                                                  | 9                 |
| Released/elite cultivar/morphological variants | 36                | High protein content                                              | 9                 |
| <b>Trait specific</b>                          |                   | Interspecific derivatives                                         | 5                 |
| Resistant to biotic stresses                   | 104               | Accessions earlier genotyped (Morag Ferguson)                     | 18                |
| Resistant to abiotic stresses                  | 40                | Accessions of 14 Wild <i>Arachis</i> species                      | 52                |
| Fresh seed dormancy                            | 6                 |                                                                   |                   |
| <b>EMBRAPA</b>                                 |                   |                                                                   |                   |
| Accessions of Wild <i>Arachis</i> species      | 62                | Cultivated accessions from diverse origin and botanical varieties | 130               |

**Table 2. Range and means in groundnut composite collection at ICRISAT Patancheru.**

| Characters                                                   | Minimum |           | Maximum |           | Mean    |           |
|--------------------------------------------------------------|---------|-----------|---------|-----------|---------|-----------|
|                                                              | Rainy   | Postrainy | Rainy   | Postrainy | Rainy   | Postrainy |
| Days to 50% emergence                                        | 7       | 8         | 9       | 13        | 8       | 10        |
| Days to 50% flowering                                        | 19      | 27        | 34      | 48        | 25      | 33        |
| Plant height (cm)                                            | 9       | 4         | 52      | 45        | 28.49   | 23.97     |
| Primary branches (no.)                                       | 2       | 3         | 9       | 9         | 5.02    | 5.16      |
| Leaflet length (mm)                                          | 32      | 29        | 87      | 93        | 56.28   | 54.56     |
| Leaflet width (mm)                                           | 13      | 12        | 41      | 45        | 25.31   | 25.41     |
| Days to maturity                                             | 100     | 103       | 130     | 133       | 106     | 123       |
| Pods plant <sup>-1</sup> (no.)                               | 2.2     | 5.5       | 64      | 41.8      | 19.82   | 18.62     |
| Pod length (mm)                                              | 14.7    | 17        | 52.5    | 65.5      | 28.19   | 30.87     |
| Pod width (mm)                                               | 8.2     | 9         | 18      | 132       | 12.37   | 13.43     |
| Seed length (mm)                                             | 8.5     | 8.5       | 318.4   | 133       | 13.69   | 14.66     |
| Seed width (mm)                                              | 5.5     | 6         | 11.4    | 14        | 7.95    | 8.82      |
| Pod yield plant <sup>-1</sup> (g)                            | 2.6     | 3.4       | 33.08   | 50.8      | 19.69   | 21.51     |
| Pod yield (kg ha <sup>-1</sup> )                             | 441.7   | 491.7     | 4068.3  | 5275.0    | 2782.34 | 2867.45   |
| Shelling percentage                                          | 35      | 43.7      | 78      | 79        | 66.71   | 70.03     |
| 100-seed weight (g)                                          | 18      | 18        | 97      | 113       | 49.43   | 60.25     |
| SPAD chlorophyll meter reading at 60 days after sowing (DAS) | 27.4    | -         | 61.38   |           | 44.08   | -         |
| Specific leaf area (60 DAS)                                  | 112.736 | -         | 268.07  |           | 187.40  | -         |
| SPAD chlorophyll meter reading (80 DAS)                      | 22.44   | -         | 56.32   |           | 42.48   | -         |
| Specific leaf area (80 DAS)                                  | 94.7224 | -         | 263.437 |           | 177.12  | -         |

- = not recorded

**Pigeonpea:** A composite collection consisting of 1000 accessions was constituted based on phenotypic, taxonomic and characterization/evaluation data. The composite collection included accessions from the mini-core collection (146), mini-core comparator (146), core collection (236), superior morpho-agronomic traits (301), resistant to biotic stresses (74), resistant to abiotic stresses (14), elite/released cultivars (20) and 63 accessions of 7 wild species (Table 3). The pigeonpea composite set was evaluated in an augmented design using four control cultivars (UPAS 120, ICPL 87, Maruti and Gwalior 3) during rainy season at ICRISAT farm, Patancheru. Observations were recorded on 3 representative plants for 16 quantitative and 16 qualitative traits. Analysis of morpho-agronomic data revealed wide range of diversity for important traits (Table 4).

**Table 3. Composite collection of pigeonpea.**

| Type of material      | No. of accessions | Type of material                 | No. of accessions |
|-----------------------|-------------------|----------------------------------|-------------------|
| Mini core collection  | 146               | Abiotic stresses                 | 14                |
| Comparator            | 146               | Drought                          | 7                 |
| Checks                | 4                 | Water logging                    | 3                 |
| Resistant sources:    |                   | Salinity                         | 4                 |
| Biotic stresses       | 75                | <i>Trait specific selections</i> | 306               |
| Pod borer             | 20                | High nodulation                  | 2                 |
| Pod fly               | 5                 | Photoperiod insensitive          | 4                 |
| Pod borer and pod fly | 4                 | Agroforestry                     | 7                 |
| Wilt                  | 6                 | Forage                           | 6                 |
| Sterility mosaic      | 16                | Vegetable                        | 7                 |
| Alternaria blight     | 7                 | High protein                     | 20                |
| Phytophthora blight   | 6                 | Released cultivars               | 16                |
| Stem canker           | 5                 | Morpho-agronomic traits          | 244               |

|           |   |              |     |
|-----------|---|--------------|-----|
| Nematodes | 6 | Wild species | 65  |
|           |   | Others       | 244 |

**Table 4. Mean and range of diversity in pigeonpea composite collection.**

| Trait                              | Minimum | Maximum | Mean  |
|------------------------------------|---------|---------|-------|
| Leaf area (cm <sup>2</sup> )       | 3.4     | 98.1    | 22.3  |
| Days to 50% flowering              | 84.9    | 162.4   | 129.2 |
| Plant height (cm)                  | 81.2    | 207.0   | 152.7 |
| Primary branches per plant (no.)   | 6.5     | 24.0    | 12.8  |
| Secondary branches per plant (no.) | 3.0     | 35.1    | 8.7   |
| Tertiary branches per plant (no.)  | 0.8     | 5.0     | 2.0   |
| Days to 75% maturity               | 161.8   | 207.1   | 187.5 |
| No of racemes per plant            | 16.0    | 195.8   | 70.1  |
| Pod bearing length (cm)            | 40.1    | 84.0    | 62.3  |
| No of pods per plant               | 26.2    | 392.7   | 143.2 |
| Pod length (cm)                    | 3.0     | 8.8     | 5.1   |
| Seeds per pod (no.)                | 3.3     | 4.6     | 3.8   |
| 100-seed weight (g)                | 3.9     | 20.7    | 9.0   |
| Seed yield per plant (g)           | 35.0    | 176.2   | 87.1  |
| Harvest index (%)                  | 24.3    | 26.5    | 25.1  |
| Shelling percentage (%)            | 53.2    | 60.7    | 57.7  |

**Pearl millet:** The pearl millet composite collection of 1000 accessions, which include core collection (504 accessions), biotic resistant sources (108 accessions), abiotic resistant sources (29 accessions), trait specific selections (247 accessions), released cultivars (5 accessions) breeding lines (47) and wild relatives (60 accessions) (Table 5). Composite collection was grown for characterization and regeneration during the rainy season in an augmented design using three control cultivars IP 17862 (ICTP 8203), IP 22281 and IP 3616, at ICRISAT, Patancheru. Observations were recorded on five representative plants in each accession for 18 morphoagronomic traits. Analysis of data revealed wide range of variation in the composite collection (Table 6).

**Table 5. Composition of pearl millet composite collection.**

| Type of material                         | No. of accessions |
|------------------------------------------|-------------------|
| Core collection                          | 504               |
| Tolerant to abiotic stresses             |                   |
| Drought                                  | 6                 |
| Heat                                     | 3                 |
| Salinity                                 | 20                |
| Resistant to biotic stresses             |                   |
| Downy mildew                             | 42                |
| Ergot                                    | 20                |
| Rust                                     | 23                |
| Smut                                     | 15                |
| Multiple disease resistant               | 8                 |
| High seed iron and zinc content (>42ppm) | 4                 |
| High seed protein (>17%)                 | 20                |
| Yellow endosperm                         | 2                 |
| Trait-specific selections                | 197               |
| Sweet stalks                             | 12                |
| Forage type                              | 8                 |
| Released cultivars                       | 5                 |
| Gene pools                               | 4                 |
| Wild relatives                           |                   |

|                                    |             |
|------------------------------------|-------------|
| <i>P. mollissimum</i>              | 6           |
| <i>P. orientale</i>                | 1           |
| <i>P. pedicellatum</i>             | 15          |
| <i>P. polystachion</i>             | 15          |
| <i>P. ramosum</i>                  | 2           |
| <i>P. schweinfurthii</i>           | 1           |
| <i>P. violaceum</i>                | 20          |
| Contribution from crop improvement | 47          |
| <b>Total</b>                       | <b>1000</b> |

**Table 6. Range of variation in pearl millet composite collection evaluated in the rainy season.**

| Trait                                     | Minimum | Maximum | Mean   |
|-------------------------------------------|---------|---------|--------|
| Days to 50% flowering                     | 36      | 139     | 53.17  |
| Plant height (cm)                         | 22      | 241     | 158.68 |
| Total tillers (no.)                       | 1.0     | 8.0     | 1.56   |
| Productive tillers (no.)                  | 0.0     | 4.6     | 1.41   |
| Nodal tillers (no.)                       | 0.0     | 7.0     | 0.13   |
| Panicle exertion (cm)                     | -18.4   | 13.0    | 2.30   |
| Panicle length (cm)                       | 4.4     | 65.2    | 22.05  |
| Panicle width (mm)                        | 7.6     | 36.4    | 19.75  |
| 1000-seed weight (g)                      | 2.0     | 18.0    | 7.59   |
| Synchrony of panicle maturity (1-9 scale) | 2       | 8       | 4.94   |
| Panicle density (1-9 scale)               | 2       | 7       | 4.40   |
| Bristle length (1-9 scale)                | 1       | 6       | 1.49   |
| Fodder yield potential (1-9 scale)        | 2       | 8       | 4.50   |
| Seed yield potential (1-9 scale)          | 2       | 8       | 4.23   |
| Overall plant aspect (1-9 scale)          | 2       | 7       | 4.59   |

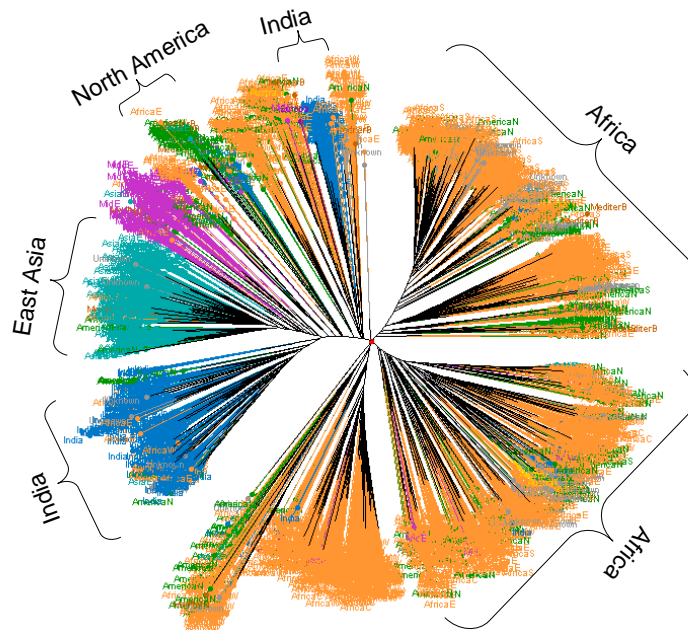
### **Output target 2.3.2: Diversity and population structure of sorghum composite collection analyzed and reference set (300 accessions) established**

#### **Diversity and population structure of sorghum composite collection**

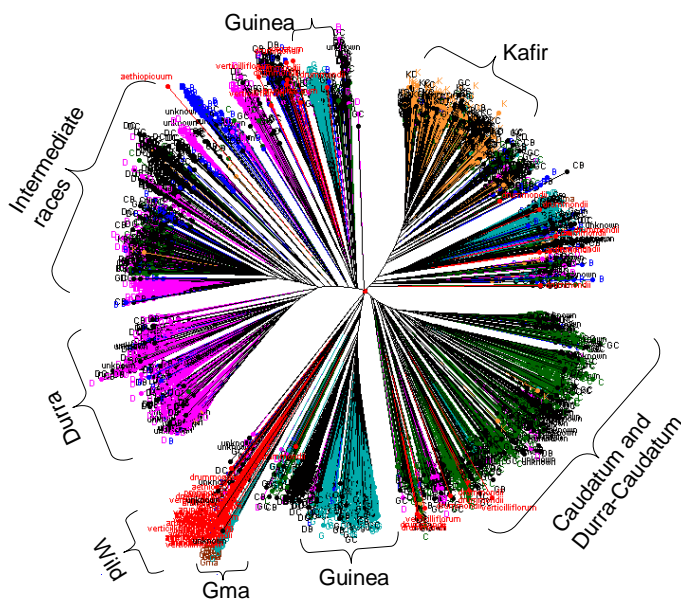
The GCP Global Composite Germplasm Collection of 3372 wild and cultivated sorghums includes 280 elite breeding lines and improved cultivars, 64 wild accessions, and >3000 landrace accessions selected from previously defined core collections, for resistance/tolerance to production constraints, and/or for variation in other traits. A set of 48 sorghum SSR markers distributed across all ten linkage groups was chosen following preliminary analysis of 48 diverse genotypes with 104 available SSRs complemented by additional SSRs from CIRAD and ICRISAT. Diversity analysis was performed on 3367 accessions genotyped with 41 SSRs by CIRAD and ICRISAT. Breeding lines and wild accessions clustered separately from landraces, which exhibited structure explainable by geographic origin (Figure 1). Landrace population and wild accession substructure was further characterized within racial groups [five basic races and ten hybrid races]. Race *bicolor* showed little evidence of population structure, congruent with it being the original domesticate. Race *kafir* (largely from Southern Africa) was distinct (Figure 2). Accessions of the *durra*, *caudatum* and *guinea* races each formed several distinct geographic subgroups. The *guinea* race *margaritifera* group formed its own cluster, with the major cluster of wild accessions, suggesting independent domestication. Intermediate races behaved similarly. With all these 41 SSRs, 789 alleles were produced in sorghum global germplasm collection with an average of 19.24 alleles per markers with average polymorphic information content (PIC) of 0.6375. Sb5-206 markers produced higher PIC value (0.9382) with higher number of alleles (34). The average gene diversity among the global composite collection is 0.6743. Accessions from the African continent contributed 87.3 % (689 alleles) of genetic diversity whereas Asia contributed 612 alleles (77.5 %) to the global composite collection.

A sorghum SSR kit was developed and information regarding the SSR kit is available at [http://sat.cirad.fr/sat/sorghum\\_SSR\\_kit/](http://sat.cirad.fr/sat/sorghum_SSR_kit/) and contains SSR primer sequence information, experimental protocol as well as details on expected allele sizes (based on sequencing) of PCR products for 10 diverse control

accessions used to produce 3 control pools. These controlled genotypes will acts as a reference kit for any diversity analysis in sorghum.



**Figure1. Radial view of cluster analysis of global germplasm collection of sorghum using 41 SSR markers, based on geographic origin.**



**Figure2. Radial view of cluster analysis of global germplasm collection of sorghum using 41 SSR markers, based on their race.**

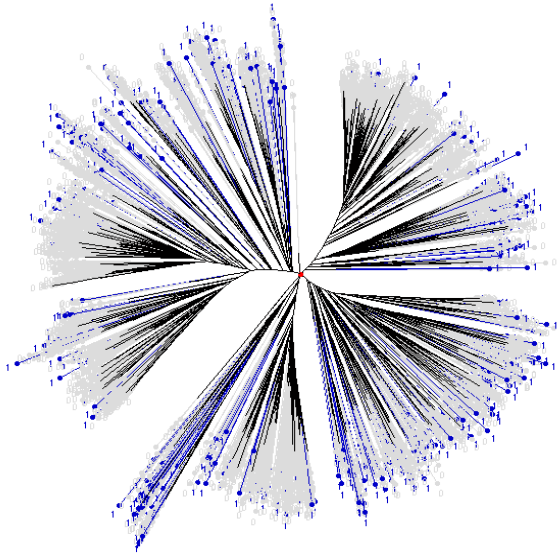
### Sorghum reference set

A reference set of 384 accessions (Figure 3) was then defined for allele mining which captured 78% of alleles (615 alleles) produced in composite germplasm collection. This set consisting of 23 wild, 4 advanced cultivars, 25 breeding materials and 332 landraces. The average gene diversity among the reference set is 0.713 with an average PIC value 0.679, which is equal to global composite collection (Table 7). Reference set is being used for allele mining under ADOC project. From this set, we have identified a representative sample of 48

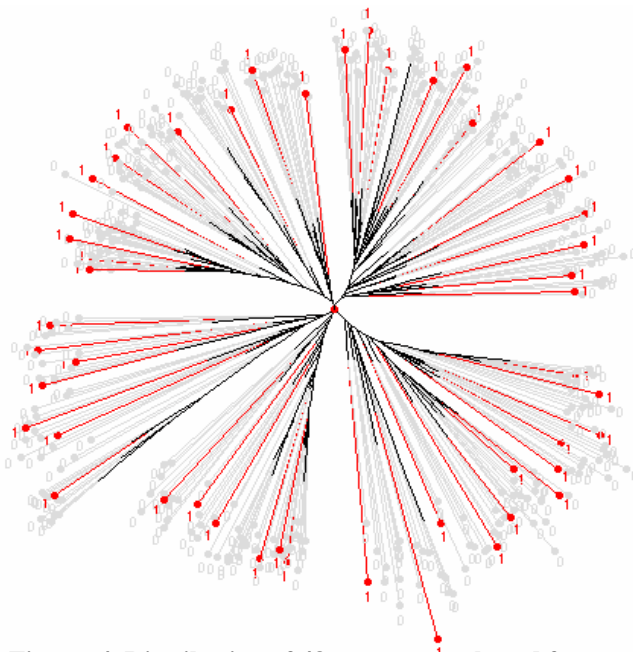
accessions (Figure 4) for use in marker genotype validation and as a smaller set with which to begin exploration of global sorghum germplasm.

**Table 7. Alleles, PIC value and gene diversity in the composite collection and reference set of sorghum.**

|                        | <b>Composite collection</b> | <b>Reference set</b> |
|------------------------|-----------------------------|----------------------|
| No. of Accessions      | 3367                        | 384                  |
| No. of Alleles         | 789                         | 615                  |
| Average PIC value      | 0.638                       | 0.679                |
| Average Gene Diversity | 0.674                       | 0.713                |



**Figure 3. Distribution of reference set representing sorghum global composite germplasm diversity.**



**Figure 4. Distribution of 48 genotypes selected for validation project from reference subset of sorghum**

**Output target 2.4.1: Genetic diversity and population structure of chickpea assessed using composite collection**

**Genetic diversity in the chickpea composite collection:**

Chickpea composite collection consisting of 3000 accessions was genotyped with 50 SSR markers. Prior to analysis, the marker quality was checked using Allelobin software. Except for the marker TA28 (quality index as determined by its standard deviation,  $S_w = 0.536$ ), all other markers detected allele size expected on the basis of SSR repeat motif. Further, marker TR2 was dropped from the analysis as it showed very high level of heterozygosity (79.5%) while % heterozygosity for the other markers was  $\leq 3.2\%$  (likely due to a duplicate locus nature of TR2). A complete data set of 49 SSR loci on 2915 accessions of the composite collection was used for statistical analysis using PowerMarker V3.0 (<http://www.powermarker.net>) for estimating basic statistics [PIC, allelic richness as determined by a total number of the detected alleles and a number of alleles per locus, gene diversity ( $H_e$ ), occurrence of unique allele, rare and common alleles, and heterozygosity (%)] and DARwin-5.0 program for depicting the genetic structure of the composite collection and reference set.

The composite collection showed rich allelic diversity (1741 alleles, 35 alleles per locus, 968 rare and 773 common alleles). The gene diversity varied from 0.534 to 0.975, and the % heterozygosity ranged between 0.00 to 3.23% (Table 8). Average heterozygosity was maximum (11.51%) in wild types and ranged between 2.10% and 2.68% in desi, kabuli and pea types. Most of the markers, except CaSTMS21, NCPGR4, NCPGR6, NCPGR7, NCPGR19, TA142, TA3, and TS84, showed high PIC values (0.8135 to 0.9740), thus highly polymorphic.

The group-specific unique alleles were 114 in Kabuli, 306 in desi, 71 in wild *Cicer*, 117 in Mediterranean, 120 in West Asia (WA), and 119 in South and Southeast Asia (SSEA) (Table 9). Kabuli types as a group were more genetically diverse than other types. Only five alleles in pea-shaped chickpea differentiated it from other seed types. SSEA and WA shared 76, Mediterranean and SSEA 33, and Mediterranean and WA regions 39 common alleles. Desi and kabuli types shared 450 alleles.

A reference set consisting of 300 genetically diverse accessions was formed (based on simple matching distance matrix), capturing 1360 (78%) of the 1741 alleles detected in the composite collection, and possessing high gene diversity (0.540 to 0.999). A tree diagram (Figure 5) of the composite collection revealed two distinct clusters each in kabuli and desi types; however, a number of desi chickpeas also grouped into kabuli cluster and vice versa. The pea-shaped types were dispersed in both the groups. Most wild *Cicer* accessions formed one group within the cluster showing majority of the kabuli chickpea accessions. A tree diagram of this reference set (Figure 6) represented diversity from all directions of the original tree diagram of the composite collection (Figure 5).

**Table 8. Allelic composition, polymorphic information content (PIC), gene diversity, and heterozygosity (%) of the 49 SSR loci in global composite collection of chickpea.**

| Marker   | Allelic composition |                 |                  |                    |              | PIC  | Gene diversity | Heterozygosity (%) |      |
|----------|---------------------|-----------------|------------------|--------------------|--------------|------|----------------|--------------------|------|
|          | Allelic richness    | Size range (bp) | Rare allele (1%) | Common allele (1%) | Major allele |      |                |                    |      |
| CaSTMS2  | 29                  | 212-326         | 10               | 19                 | 245          | 10.3 | 0.929          | 0.933              | 2.43 |
| CaSTMS15 | 29                  | 209-368         | 13               | 16                 | 248          | 15.5 | 0.904          | 0.911              | 1.85 |
| CaSTMS21 | 20                  | 150-210         | 16               | 4                  | 168          | 61.7 | 0.468          | 0.534              | 0.17 |
| NCPGR4   | 14                  | 149-201         | 10               | 4                  | 193          | 52.6 | 0.606          | 0.650              | 0.21 |
| NCPGR6   | 21                  | 213-361         | 18               | 3                  | 255          | 48.9 | 0.559          | 0.628              | 0.11 |
| NCPGR7   | 15                  | 201-243         | 11               | 4                  | 223          | 49.8 | 0.549          | 0.619              | 0.11 |
| NCPGR12  | 27                  | 214-272         | 15               | 12                 | 254          | 28.8 | 0.813          | 0.832              | 0.14 |
| NCPGR19  | 26                  | 288-464         | 20               | 6                  | 300          | 45.8 | 0.591          | 0.652              | 0.11 |
| TA2      | 67                  | 93-251          | 47               | 20                 | 135          | 7.8  | 0.948          | 0.950              | 0.00 |
| TA3      | 29                  | 205-305         | 21               | 8                  | 293          | 30.6 | 0.727          | 0.764              | 0.00 |
| TA5      | 43                  | 155-293         | 30               | 13                 | 200          | 14.4 | 0.909          | 0.915              | 0.00 |
| TA8      | 33                  | 174-280         | 14               | 19                 | 204          | 12.7 | 0.913          | 0.919              | 0.00 |
| TA11     | 29                  | 158-296         | 17               | 12                 | 236          | 19.0 | 0.871          | 0.882              | 0.00 |

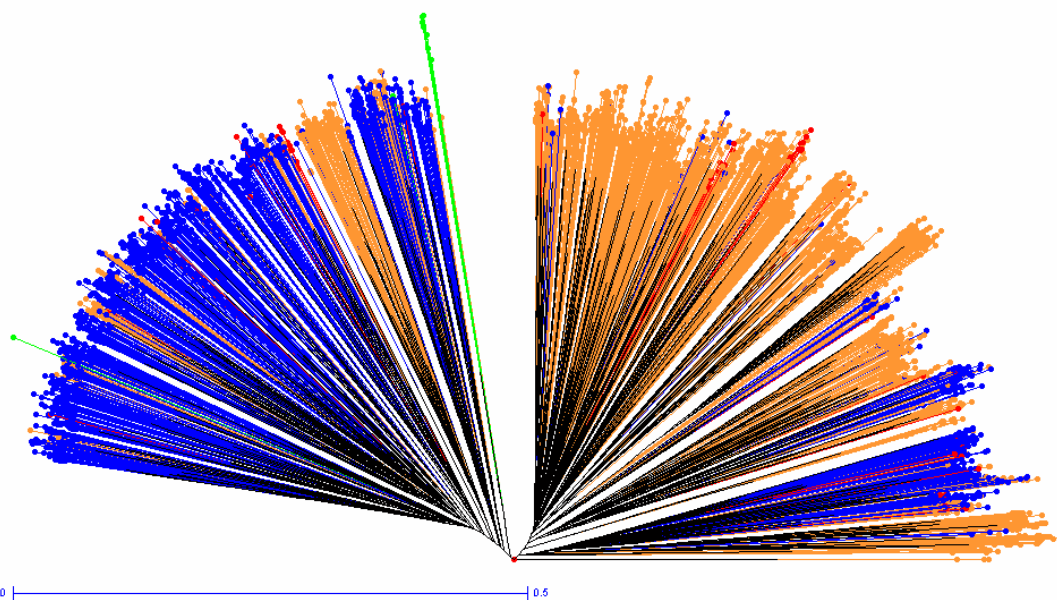


|              |             |         |            |            |     |      |       |       |      |
|--------------|-------------|---------|------------|------------|-----|------|-------|-------|------|
| TA14         | 41          | 210-354 | 23         | 18         | 267 | 14.2 | 0.904 | 0.911 | 0.80 |
| TA21         | 42          | 275-422 | 21         | 21         | 350 | 9.3  | 0.938 | 0.941 | 0.62 |
| TA22         | 50          | 131-344 | 17         | 33         | 203 | 7.7  | 0.962 | 0.964 | 0.40 |
| TA27         | 32          | 192-306 | 19         | 13         | 240 | 16.5 | 0.891 | 0.899 | 0.75 |
| TA28         | 58          | 231-438 | 33         | 25         | 336 | 8.5  | 0.958 | 0.960 | 0.25 |
| TA42         | 46          | 101-251 | 27         | 19         | 179 | 10.7 | 0.936 | 0.940 | 0.00 |
| TA46         | 24          | 126-195 | 11         | 13         | 153 | 21.7 | 0.843 | 0.858 | 0.34 |
| TA64         | 36          | 173-284 | 15         | 21         | 239 | 9.8  | 0.943 | 0.945 | 3.23 |
| TA71         | 41          | 139-277 | 25         | 16         | 202 | 13.9 | 0.917 | 0.922 | 0.85 |
| TA72         | 45          | 177-375 | 33         | 12         | 243 | 18.6 | 0.875 | 0.885 | 0.46 |
| TA76s        | 34          | 149-314 | 24         | 10         | 212 | 24.3 | 0.813 | 0.834 | 2.37 |
| TA78         | 39          | 95-262  | 21         | 18         | 199 | 14.9 | 0.905 | 0.911 | 0.00 |
| TA80         | 35          | 148-275 | 16         | 19         | 199 | 12.4 | 0.927 | 0.931 | 0.00 |
| TA96         | 48          | 161-324 | 29         | 19         | 275 | 14.0 | 0.918 | 0.923 | 0.00 |
| TA113        | 19          | 151-238 | 8          | 11         | 202 | 27.6 | 0.851 | 0.863 | 1.63 |
| TA116        | 33          | 159-276 | 22         | 11         | 180 | 22.3 | 0.838 | 0.853 | 0.89 |
| TA117        | 36          | 173-323 | 18         | 18         | 248 | 9.8  | 0.929 | 0.933 | 0.62 |
| TA118        | 43          | 116-263 | 18         | 25         | 182 | 9.9  | 0.949 | 0.952 | 1.55 |
| TA130        | 23          | 185-254 | 10         | 13         | 221 | 34.0 | 0.822 | 0.835 | 1.19 |
| TA135        | 21          | 125-221 | 8          | 13         | 194 | 24.6 | 0.850 | 0.864 | 2.70 |
| TA142        | 23          | 113-197 | 14         | 9          | 128 | 36.2 | 0.758 | 0.785 | 0.57 |
| TA144        | 56          | 179-287 | 37         | 19         | 239 | 16.2 | 0.931 | 0.935 | 0.00 |
| TA176        | 64          | 146-365 | 25         | 39         | 221 | 5.6  | 0.974 | 0.975 | 0.00 |
| TA194        | 29          | 87-291  | 17         | 12         | 96  | 26.3 | 0.867 | 0.877 | 0.00 |
| TA200        | 39          | 250-379 | 23         | 16         | 286 | 15.9 | 0.917 | 0.922 | 1.71 |
| TA203        | 56          | 160-294 | 27         | 29         | 214 | 5.8  | 0.964 | 0.965 | 0.00 |
| TA206        | 32          | 350-449 | 18         | 14         | 386 | 16.1 | 0.898 | 0.906 | 0.71 |
| TAA58        | 45          | 205-349 | 21         | 24         | 274 | 7.2  | 0.956 | 0.957 | 1.33 |
| TAASH        | 39          | 364-496 | 20         | 19         | 436 | 10.6 | 0.930 | 0.934 | 0.70 |
| TR1          | 62          | 133-324 | 45         | 17         | 200 | 11.4 | 0.929 | 0.934 | 0.00 |
| TR7          | 26          | 167-248 | 8          | 18         | 206 | 16.7 | 0.891 | 0.899 | 2.44 |
| TR29         | 32          | 127-259 | 15         | 17         | 217 | 15.0 | 0.916 | 0.921 | 2.08 |
| TR31         | 16          | 165-324 | 7          | 9          | 201 | 22.8 | 0.843 | 0.859 | 2.66 |
| TR43         | 53          | 249-474 | 26         | 27         | 300 | 7.0  | 0.956 | 0.958 | 2.45 |
| TS45         | 26          | 134-274 | 17         | 9          | 244 | 21.6 | 0.842 | 0.858 | 0.00 |
| TS84         | 15          | 197-266 | 8          | 7          | 227 | 44.4 | 0.596 | 0.656 | 0.32 |
| <b>Total</b> | <b>1741</b> |         | <b>968</b> | <b>773</b> |     |      |       |       |      |
| <b>Mean</b>  | <b>35</b>   |         |            |            |     |      |       |       |      |

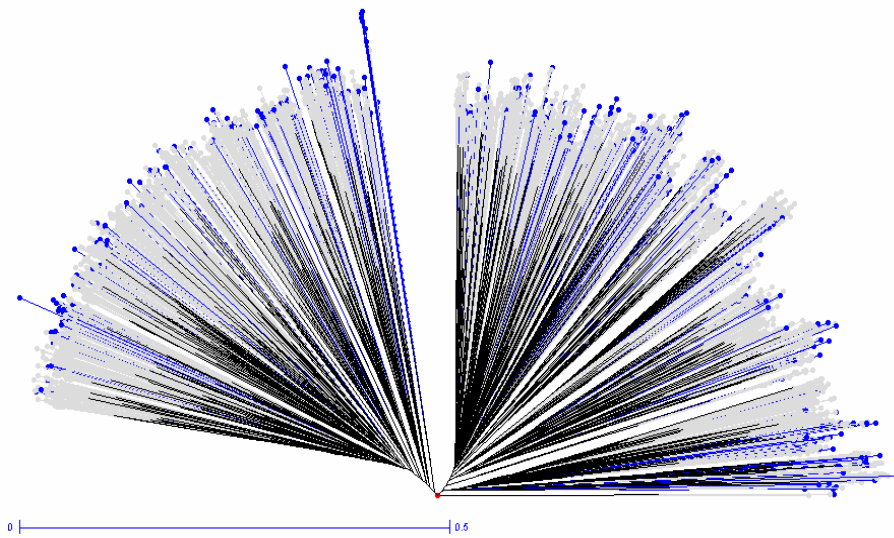
**Table 9. Molecular diversity of accessions related to their biological and geographical classification of the 2915 accessions included in chickpea composite collection.**

| Biological classification          | Number of accessions | Allelic composition    |                    |                  |               | Gene diversity      | Heterozygosity (%) |
|------------------------------------|----------------------|------------------------|--------------------|------------------|---------------|---------------------|--------------------|
|                                    |                      | Allelic richness       | Common allele (1%) | Rare allele (1%) | Unique allele |                     |                    |
| <b>Biological classification</b>   |                      |                        |                    |                  |               |                     |                    |
| Kabuli                             | 1167                 | 1333 (27) <sup>+</sup> | 716                | 617              | 114           | 0.849(0.254-0.964)  | 2.68               |
| Desi                               | 1668                 | 1525 (31)              | 726                | 799              | 306           | 0.850 (0.417-0.974) | 2.10               |
| Pea-shaped                         | 70                   | 691 (14)               | 684                | 7                | 5             | 0.842 (0.484-0.955) | 2.18               |
| <b>Wild <i>Cicer</i> species</b>   | 10                   | 349 (7)                | 349                | 0                | 71            | 0.794 (0.444-0.890) | 11.51              |
| <b>Geographical classification</b> |                      |                        |                    |                  |               |                     |                    |
| Africa                             | 150                  | 858 (18)               | 655                | 203              | 10            | 0.806 (0.301-0.949) | 1.90               |
| CIS                                | 44                   | 598 (12)               | 598                | 0                | 0             | 0.799 (0.376-0.799) | 2.83               |
| Europe                             | 65                   | 669 (14)               | 663                | 6                | 3             | 0.809 (0.175-0.936) | 2.37               |
| Mediterranean                      | 619                  | 1324 (26)              | 712                | 612              | 117           | 0.836 (0.260-0.965) | 2.97               |
| North and central America          | 94                   | 747 (15)               | 747                | 0                | 6             | 0.834 (0.467-0.948) | 1.89               |
| South America                      | 49                   | 541 (11)               | 541                | 0                | 3             | 0.777 (0.119-0.941) | 2.39               |
| South and southeast Asia           | 1138                 | 1367 (28)              | 671                | 696              | 119           | 0.826 (0.347-0.969) | 2.13               |
| Unknown region                     | 34                   | 602 (12)               | 602                | 0                | 15            | 0.853 (0.545-0.939) | 1.71               |
| West Asia                          | 720                  | 1369 (28)              | 811                | 558              | 120           | 0.869 (0.478-0.967) | 2.37               |

<sup>+</sup> Average number of alleles



**Figure 5. Radial diagram of composite collection (49 SSR loci data on 2915 accessions) showing desi (orange color), kabuli (blue color), pea shaped (red color) and wild types (green color) as revealed by DARwin-5.**



**Figure 6. 300 accessions representing reference set (blue color) and the remaining 2615 accessions of the composite collection (gray color)**

***Output target A.1: New germplasm of staple crops assembled for conservation and utilization (2009)***

**Activity A.1.1: Identify gaps and priority areas for germplasm of staple crops**

*Milestone A.1.1.1: Global databases of chickpea and pigeonpea compared to identify unique germplasm (HDU, 2007)*

Germplasm databases of chickpea at ICRISAT and the National Centre for Plant Genetic Resources of Ukraine (NCPGRU) were compared and 313 accessions identified as being unique for inclusion in our collection. We have secured 72 accessions for planting and further release by NBPGR. We continue our efforts in getting the remaining germplasm from Ukraine. Similarly, we also compared our chickpea database with collections at ICARDA, Syria and USDA, USA for identifying unique material especially wild *Cicer* for inclusion in our collection. Strengthening the pigeonpea germplasm database at ICRISAT was emphasized during the Global Germplasm Conservation Strategies meetings in 2006. The pigeonpea germplasm database of ICRISAT were compared with the ICRISAT collection at Nairobi and the National Dryland Farming Research Station (NDFRS), Kenya, Australian Tropical Crops Genetic Resource Centre, Australia and with national collections in India at the Indian Institute of Pulses Research, Kanpur and Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Sehore to identify unique germplasm for assembly at Patancheru. These efforts have resulted in identifying several germplasm accessions especially in filling gaps for traits like plant type and maturity in both the crops.

HD Upadhyaya

*Milestone A.1.1.2: Priority areas identified for chickpea and pigeonpea for collection/assembly in collaboration with NARS (HDU/NARS scientists, 2008)*

No report for 2007

*Milestone A.1.1.3: Sorghum germplasm from USDA (500 accessions), pearl millet from Niger (400 accessions) and pigeonpea collections from Tanzania, Uganda and Mozambique (200 accessions) assembled (HDU/CLLG, 2008)*

National Bureau of Plant Genetic Resources (NBPGR), India has released 21 germplasm samples of sorghum received from USDA, USA and 423 pearl millet collections from Niger for growing in Post Entry Quarantine Isolation area (PEQIA) for observation and subsequent release. We have initiated steps to acquire remaining sorghum accessions from the USDA. Passport database of pearl millet germplasm at ICRISAT-Patancheru was compared with ICRISAT-Niamey database and a total of 390 accessions identified as unique. The pearl millet collection at IER, Mali was compared and 504 accessions identified as unique for inclusion in the collection at ICRISAT genebank. We have received import permits from the Government of India for acquiring pigeonpea (231) collections from Tanzania, Uganda and Mozambique held at Nairobi genebank. These are expected for planting and further release in 2008.

HD Upadhyaya and CLL Gowda

*Milestone A.1.1.4: Global databases of groundnut and sorghum compared to identify unique germplasm (HDU, 2008)*

Sorghum germplasm databases of ICRISAT and the USDA maintained at NSSL, Fort Collins, USA were compared and 2708 accessions identified of the Rockefeller collection that were missing from our collection. A set of 619 accessions from the newly identified set of 2708 accessions, was assembled and added to the collection. This year, an additional 21 accessions were secured. We are making efforts for obtaining the remaining accessions for filling gaps in the collection. The germplasm database of Chinese Academy of Agricultural Sciences (CAAS), China was compared with our database and 250 accessions of sorghum identified belonging to race *Caudatum* and subrace *Kaoliang* and 250 accessions of groundnut germplasm belonging to botanical variety *hirsuta* as unique for ICRISAT genebank. We have made formal requests for securing these collections from CAAS, China and secured 25 accessions of sorghum during this year.

HD Upadhyaya

*Milestone A.1.1.5: Priority areas identified for groundnut and sorghum for collection/assembly in collaboration with NARS (HDU/NARS scientists, 2009)*

No report for 2007

**Output target A.2: Assembled germplasm of staple crops characterized for utilization (2009)**

**Activity A.2.1: Characterize new germplasm for important morpho-agronomic traits**

*Milestone A.2.1.1: Sorghum germplasm from Niger (450 accessions), chickpea germplasm from ICARDA (500 accessions) and groundnut germplasm from Japan assembled and characterized for morpho-agronomic traits (HDU/CLLG, 2008)*

Sorghum germplasm from Niger (482 accessions) was planted for characterization during rainy and post-rainy seasons. The crop establishment is excellent for recording descriptors for characterization following Sorghum Descriptors. Observation recording is in progress on important morpho-agronomic traits like days to flowering, plant height, panicle exertion, ear head length, and ear head width. In our preliminary characterization during 2006 post-rainy season, the data on classification of this collection revealed that four basic races (*bicolor*, *guinea*, *caudatum* and *durra*) and intermediate races *guinea-caudatum*, *caudatum-bicolor*, *durra-bicolor*, *kafir-caudatum* and *durra-caudatum* were available in this collection. We also identified eleven large glumes and eight yellow endosperm accessions in this set for use in crop improvement. During this year, we characterized 747 chickpea accessions assembled from USA and 468 other accessions for updating databases in the post-rainy season. These accessions would be characterized for all the qualitative and quantitative traits following ICRISAT-IBPGR Descriptors. Data recording is in progress. We also characterized 417 accessions assembled from ICARDA in the field during 2006-07 post-rainy season and regenerated 14 accessions with limited seed quantities for seed multiplication in the glasshouse. The characterized set represents 384 kabuli type, 26 desi type and seven intermediate type accessions. These characterization traits included, days to 50% flowering, days to flower ending, flowering duration, flower color, plant color, plant height, plant width, growth habit, days to maturity, number of basal primary branches, number of apical primary branches, number of basal secondary branches, number of apical secondary branches, number of tertiary branches, seed color, seed shape, seed texture, dots on seed color, pods per plant, 100-seed weight and yield per plant. This has resulted in identifying several promising sources for further testing and utilization. These include, 12 accessions with 100-seed weight >50 g, five accessions with high yield potential (2.73 to 2.85 t ha<sup>-1</sup>) and five other accessions having combination of large seed size (100-seed size >40g) and high yield potential (2.14 to 2.82 t ha<sup>-1</sup>). We regenerated, 47 groundnut germplasm samples received (disease free seeds) from National Institute of Aerobiological Sciences (NIAS), Japan for further characterization. The remaining accessions (400 groundnut accessions) have also been released by the NBPGR for observations, seed increase and detailed characterization for morphological and agronomic traits. Additionally, we grew 242 mini-core sorghum germplasm accessions during the rainy season for collecting data on days to 50% flowering, plant height, plant pigmentation, midrib color, exertion, ear head length and width.

HD Upadhyaya and CLL Gowda

*Milestone A.2.1.2: Sorghum germplasm from USDA, pearl millet collections from Niger (400 accessions), and pigeonpea collections from Tanzania, Uganda and Mozambique (200 accessions) characterized (HDU/CLLG, 2009)*

Sorghum germplasm received from USDA (21 samples) were planted in isolation for seed increase and further characterization during 2008 rainy and post-rainy seasons. The pearl millet collections from Niger and pigeonpea collections from Tanzania, Uganda and Mozambique which are at different stages of release by NBPGR to ICRISAT will be characterized during 2008.

HD Upadhyaya and CLL Gowda

*Milestone A.2.1.3: Morpho-agronomic characterization of 420 sorghum landraces and 84 wild types from sorghum growing areas in Mali (except Gao region) with a special focus on adaptive traits (cycle, photoperiod sensitivity, tillering, stay green) (FS/PST/NARS, 2006)*

Completed and reported in 2006.

*Milestone A.2.1.4: Morpho-agronomic patterns of sorghum diversity in Mali to understand large adaptive trends and identify new interesting local germplasm for breeding programs published (FS, PST + NARS, 2008)*

Morpho-agronomical experiments completed in 2007 with a last trial established at a late sowing date to estimate the Basic Vegetative Phase (BVP) at ICRISAT Samanko on 420 sorghum varieties and 84 wild types from Mali. All data sets assembled and initial analyses initiated.

F Sagnard and PS Traoré (in collaboration with IER)

### ***Output target A.3: Germplasm sets of staple crops evaluated for useful traits (2009)***

#### **Activity A.3.1: Evaluate germplasm sets of staple crops for agronomic characters and special traits for utilization**

*Milestone: A.3.1.1: Sets of germplasm in staple crops evaluated to identify sources for yield and other quality traits (HDU/CLLG/Scientists - Crop Improvement, Annual)*

**Sorghum:** 482 new sorghum germplasm accessions received from Niger, 242 mini-core sorghum germplasm accessions and 573 photoperiod-insensitive sorghums selected from sorghum core collection were evaluated for sweet stalks (sugar content). For use in kharif season, we selected 24 new sorghum germplasm accessions from Niger, based on days to 50% flowering, plant height, exertion, ear head length and width under Kharif Basic Collection (KBC). These 24 accessions are IS 41784, IS 41798, IS 41813, IS 41827, IS 41888, IS 41903, IS 41907, IS 41908, IS 41916, IS 41919, IS 41941, IS 41967, IS 41978, IS 41990, IS 42009, IS 42016, IS 42019, IS 42032, IS 42043, IS 42067, IS 42096, IS 42103, IS 42159 and IS 42242.

**Pearl millet:** Planted 134 accessions of *Pennisetum pedicellatum*, a source for pearl millet downy mildew resistance and recording of data is in progress.

#### **Chickpea:**

**Early maturity:** Evaluated 17 germplasm accessions with ICCV 2, ICCV 96029 and Annigeri as control cultivars. ICC 14368 ( $1.93 \text{ t ha}^{-1}$ ) produced significantly greater seed yield than the high yielding control cultivar Annigeri ( $1.50 \text{ t ha}^{-1}$ ). Similarly, ICC 13044 and ICC 16347 matured in 102 days and produced 0.94 to  $1.18 \text{ t ha}^{-1}$  in comparison to ICCV 2 (108 days and  $1.13 \text{ t ha}^{-1}$ ).

**Large seeded Kabuli:** Large-seeded kabuli germplasm lines were evaluated in three trials separately with the control cultivars. In first trial, we evaluated 16 large seeded kabuli chickpea accessions with ICCV 2, JGK 1, KAK 2, and L 550 as control cultivars under late sown conditions. ICCs 14199, 14502, 16670 and 17109 with 40g to 51g 100-seed weights produced 0.55 to  $0.71 \text{ t ha}^{-1}$  in comparison to best control cultivar KAK 2 (31g;  $0.49 \text{ t ha}^{-1}$ ) and JGK 1 (31g;  $0.55 \text{ t ha}^{-1}$ ).

In the second trial, we evaluated another 34 large-seeded kabuli chickpea accessions along with ICCV 2, JGK 1, KAK 2, and L 550. ICCs 6187, 6210, 14214, and 16803 produced 1.38 to  $1.90 \text{ t ha}^{-1}$  with 36.9 – 49.1 g 100-seed weights in comparison to KAK 2 (35.4g;  $1.36 \text{ t ha}^{-1}$ ) and JGK 1 (31.3 g;  $1.11 \text{ t ha}^{-1}$ ).

In the third trial, 16 large-seeded kabuli chickpea accessions selected from the newly acquired germplasm were evaluated with ICCV 2, JGK 1, KAK 2, and L 550 under irrigated and non-irrigated environments. Under irrigated environment, ICCs 17452, 17457 and 19189 produced 1.55 to  $1.71 \text{ t ha}^{-1}$  with 51.2 to 60.6 g 100-seed weight in comparison to KAK 2 ( $1.50 \text{ t ha}^{-1}$ ; 37.8g) and JGK 1 ( $0.59 \text{ t ha}^{-1}$ ; 31.6 g). Under non-irrigated environment, ICCs 17450, 17452, 17456, 17457, 17459, 18591, 19189, and 19191 produced 1.01 to  $1.61 \text{ t ha}^{-1}$  with 49.4 to 56.9 g 100-seed weight in comparison to KAK 2 ( $0.87 \text{ t ha}^{-1}$ ; 38.1g) (Table 1). ICCs 17450, 17452, and 17458 (11.1 to 16.0%) were identified as wilt tolerant in comparison to controls ICCV 2 (20.0%) and KAK 2 (16.1%).

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**Table 1. Performance of selected large-seeded kabuli chickpea accessions under irrigated and non-irrigated environments, 2006-07 Post-rainy season, ICRISAT Patancheru, India.**

| Identity          | Days to 50% flowering | 100-seed weight (g) |           |               |      | Yield (kg ha <sup>-1</sup> ) |           |                |      |
|-------------------|-----------------------|---------------------|-----------|---------------|------|------------------------------|-----------|----------------|------|
|                   |                       | Irrigated           | Irrigated | Non-irrigated | Mean | Increase over KAK 2 (%)      | Irrigated | Non-irrigated* | Mean |
| ICC19189          | 32                    | 55.0                | 53.4      | 54.2          | 42.6 | 1552                         | 1274      | 1413           | 19.0 |
| ICC17452          | 33                    | 60.6                | 54.6      | 57.6          | 51.6 | 1578                         | 1126      | 1352           | 13.8 |
| ICC17456          | 35                    | 55.3                | 51.0      | 53.2          | 39.9 | 1422                         | 1201      | 1312           | 10.4 |
| ICC17457          | 45                    | 51.2                | 48.1      | 49.7          | 30.7 | 1708                         | 1549      | 1629           | 37.1 |
| ICC18591          | 31                    | 61.6                | 56.9      | 59.3          | 55.9 | 1235                         | 1610      | 1422           | 19.7 |
| Controls          |                       |                     |           |               |      |                              |           |                |      |
| KAK 2             | 34                    | 37.8                | 38.1      | 38.0          |      | 1501                         | 874       | 1188           |      |
| L 550             | 65                    | 17.4                | 17.1      | 17.3          |      | 1500                         | 1453      | 1476           |      |
| ICCV 2            | 31                    | 21.2                | 24.1      | 22.7          |      | 1308                         | 1137      | 1223           |      |
| Trial mean        | 356                   | 46.5                |           |               |      | 1097                         |           |                |      |
| SE <sub>±</sub>   | 0.76                  | 2.76                |           |               |      | 223.3                        |           |                |      |
| CV %              | 3.0                   | 8.4                 |           |               |      | 28.8                         |           |                |      |
| *= non-replicated |                       |                     |           |               |      |                              |           |                |      |

**Evaluation of large-seeded kabuli chickpea types for drought tolerance traits:** Evaluated 50 large-seeded kabuli accessions for root length, a trait related to drought tolerance in chickpea. ICC 17450 and 17458 (58.1 and 53.1 g 100-seed weight) had the largest root length density (0.274 and 0.258 cm cm<sup>-3</sup>) in comparison to drought tolerant control ICC 4958 (0.252 cm cm<sup>-3</sup>). Both of these large-seeded accessions are tolerant to wilt also (<20% wilt).

HD Upadhyaya, J Kashiwagi, N Lalitha,  
L Krishnamurthy and S Pande

**Evaluation of salinity tolerant chickpea lines for yield:** Evaluated 52 salinity tolerant chickpea germplasm accessions with ICCV 2 and Jumbo 2 as control cultivars for yield and other agronomic traits. ICCs 7554 and 12339 (2.15 to 2.43 t ha<sup>-1</sup>) produced significantly higher seed yield than ICCV 2 (1.40 t ha<sup>-1</sup>) and Jumbo 2 (1.24 t ha<sup>-1</sup>).

HD Upadhyaya, V Vadez and L Krishnamurthy

**Evaluation of high root length density chickpea lines for yield:** Root length density is a drought tolerance related trait in chickpea. We evaluated 10 accessions each of small and large root length density along with ICC 4958, Annigeri, and ICCV 2 as control cultivars under irrigated and non-irrigated conditions. Among the large root length density accessions, ICCs 15294, 1915, and 13816 produced higher seed yield (1.31 t ha<sup>-1</sup> to 1.70 t ha<sup>-1</sup>) in comparison to drought tolerant control ICC 4958 (1.31 t ha<sup>-1</sup>) under irrigated conditions. None of the large root density accessions produced greater seed yield under non-irrigated conditions.

**Evaluation of deep root length chickpea lines for yield:** Root depth is also a drought tolerance related trait in chickpea. We evaluated 10 accessions each of large deep root and small deep root along with ICC 4958, Annigeri, and ICCV 2 as control cultivars under irrigated and non-irrigated conditions. Among the large deep rooted accessions, ICCs 440, 95, 4872, 1356 and 15697 produced higher seed yield (2.06 t ha<sup>-1</sup> to 2.51 t ha<sup>-1</sup>) in comparison to drought tolerant control ICC 4958 (1.87 t ha<sup>-1</sup>) under irrigated environment. ICC 1356 produced 1.57 t ha<sup>-1</sup> in comparison to ICC 4958 (1.40 t ha<sup>-1</sup>) under non-irrigated conditions.

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**Evaluation of newly acquired chickpea accessions from USA:** Evaluated 747 newly acquired chickpea accessions with three desi (Annigeri, G 130, and ICCV 10) and two kabuli (L 550 and KAK 2) control cultivars in an augmented design. Among desi types, PIs 578283, 595395, 543291, 583753, 577004, 557443, 572500, 594328, 572506, 572507, 595969, and 509139 (2.92 to 4.76 t ha<sup>-1</sup>) produced higher seed yield than Annigeri (2.74 t ha<sup>-1</sup>), ICCV 10 (2.89 t ha<sup>-1</sup>), and G 130 (2.18 t ha<sup>-1</sup>). Among kabuli types, IPs 468930, 595981, 533678,

587044, 502990, 533677, 503024 ( 38.5 g to 58.0 g) were larger in seed size and produced higher or similar seed yield (1.79 to 2.57 t ha<sup>-1</sup>) to KAK 2 (2.32 t ha<sup>-1</sup>; 38.3 g) and L 550 (2.05 t ha<sup>-1</sup>; 19.6g).

**Evaluation of newly acquired chickpea accessions from ICARDA:** Evaluated 500 chickpea accessions from ICRISAT genebank and 431 from ICARDA genebank in an augmented designed experiment with three desi (Annigeri, G 130, and ICCV 10) and two kabuli (L 550 and KAK 2) control cultivars. Among desi types, ICCs 517, 1273, 1503, 2950, 6067, 9006, 18213, 18218 and ICCV 93952, and IG 71756 produced 2.23 to 2.90 t ha<sup>-1</sup> in comparison to Annigeri ( 2.16 t ha<sup>-1</sup>), G 130 (1.59 t ha<sup>-1</sup>) and ICCV 10 (2.23 t ha<sup>-1</sup>). Among kabuli types, ICC 17457 and IG 70514 had higher 100-seed weight (36.3 – 36.6g) and higher seed yield (1.52-1.53 t ha<sup>-1</sup>) than the control KAK 2 (1.40 t ha<sup>-1</sup> seed yield and 34.8g 100-seed weight). Among pea-shaped types, IG 70432 (2.26 t ha<sup>-1</sup>) was identified as a high yielding accession.

HD Upadhyaya and CLL Gowda

**Evaluation of chickpea reference set:** 300 accessions of chickpea reference set was evaluated for yield and other agronomic traits with three desi (Annigeri, G 130, and ICCV 10) and two kabuli (L 550 and KAK 2) control cultivars in an augmented designed experiment. Among desi types, 24 accessions produced higher seed yield (3.05 to 4.17 t ha<sup>-1</sup>) than Annigeri (3.03 t ha<sup>-1</sup>), G 130 (2.45 t ha<sup>-1</sup>) and ICCV 10 (2.06 t ha<sup>-1</sup>). ICCs 13892, 2263, 15868, 1180, and 6802 (3.68 t ha<sup>-1</sup>) were the best five high yielding accessions among desi types. Among kabuli types, 35 accessions (2.18 to 4.18 t ha<sup>-1</sup>) produced higher seed yield than L 550 (2.10 t ha<sup>-1</sup> seed yield and 20.5 g 100-seed weight) and KAK 2 (1.78 ha<sup>-1</sup> seed yield and 38.3 g 100-seed weight). ICCs 8155, 12328, and 16654 and IG 6905 were the best large-seeded kabuli accessions (39.1 to 43.9 g) combined with higher seed yield (2.40 to 3.48 t ha<sup>-1</sup>).

HD Upadhyaya, N Lalitha and CLL Gowda

#### **Groundnut:**

**Evaluation of reference set:** Evaluated 300 accessions of groundnut reference set with control cultivars Gangapuri, M 13, ICGS 44 and ICGS 76 in augmented designed experiments during 2006-07 post-rainy and 2007 rainy seasons. ICGs 14482, 2772, 5252, 5286, 5891, 6766, and 875 produced 1.70 to 1.91 t ha<sup>-1</sup> in comparison to Gangapuri (1.13 t ha<sup>-1</sup>), M13 (1.28 t ha<sup>-1</sup>), ICGS 44 (1.66 t ha<sup>-1</sup>), and ICGS 76 (1.64 t ha<sup>-1</sup>) during 2006-07 post-rainy season. Data compilation for 2007 rainy season is in progress. We also evaluated 25 large-seeded groundnut accessions which were identified in mini-core collection, during 2007 rainy season. Data compilation is in progress.

#### **Pigeonpea:**

**Evaluation of wild species:** Planted 106 accessions of 18 *Cajanus* species for characterization and sets of vegetable type (105 accessions) and salinity tolerance (29 accessions) for evaluation during 2007 rainy season. Recording of observations is in progress in these lines.

HD Upadhyaya and CLL Gowda

**Evaluation of pigeonpea germplasm in Uganda:** *In-situ* evaluation of pigeonpea cropping system and management in Uganda and agro-morphological characterization of the collected 29 pigeonpea landraces were carried out by ICRISAT and partners. Results showed that pigeonpea in Uganda are predominantly inter-cropped with finger millet and to some extent with maize and sorghum. Farmers largely used saved grain as seed and identified the damage by pod borers, pod suckers and bruchids, but only farmers in Apach and Lira districts practiced any form of pest control. Observations across the collection districts indicated low levels of fusarium wilt disease. Pigeonpea is eaten as food in the form of green peas, dry whole grain or split (dhal). Agronomic evaluation of the 29 accessions revealed differential adaptation at the two test locations with accessions expressing a delayed phenology at the cooler Kabete relative to the warmer Kampi ya Mawe location. Lower seed mass was reported at Kabete relative to Kampi ya Mawe possibly due to excessive vegetative growth at Kabete. Cluster analysis delineated the germplasm into four clusters all separated from the adapted medium and long duration checks. Although two distinct diversity groups were observed separating the short, medium maturing types from the tall late and very late maturing types, the separation was relatively marginal suggesting a closer genetic relation between the Ugandan pigeonpea germplasm. Relatively low diversity in qualitative traits was observed in the accessions with highest diversities recorded in streak pattern, growth habit, flowering pattern, pod hairiness and seed eye color. There was a significant G x E interaction on growth habit and flowering pattern. The predominance of accessions with pubescent pods, a trait associated with resistance to pod damaging insects may provide an opportunity to identify materials for insect pest resistance for use in breeding. Delayed phenology at the cool site at Kabete indicates that the Uganda accessions have high



optimum temperature and would form a basis for breeding for climate change where mean temperatures are expected to increase.

S Silim and E Manyasa

*Milestone: A.3.1.2: New/assembled germplasm characterized/evaluated for important traits to fill gaps in characterization data (HDU, Annual)*

Sorghum germplasm from Niger (482 accessions) was planted for characterization during rainy and post-rainy seasons. Observation recording is in progress on important morpho-agronomic traits as per the descriptors list. In chickpea, we characterized 747 accessions assembled from USA, 431 from ICARDA and 468 accessions for updating databases. In pigeonpea, we characterized 866 accessions for which characterization data is incomplete and planted 692 accessions during 2007 for collecting data on missing traits. A total of 500 groundnut accessions (rainy season) and 1671 accessions (post-rainy season) were planted for recording data on missing traits. Additionally, 52 wild *Arachis* accessions were characterized for morpho-agronomic traits in special facilities.

HD Upadhyaya

*Milestone: A.3.1.3: New germplasm sources identified for target insect pests and diseases in different crops (HCS/RPT/SP/HDU/CLLG, Annual)*

**Evaluation of reference collection of chickpea for resistance to *Helicoverpa armigera*:** Chickpea reference collection (305 accessions including five controls) was evaluated for resistance to pod borer, *Helicoverpa armigera*, using detached leaf assay in the 2006/07 post-rainy season. The material was grown under field conditions, and terminal branches (5 – 7 cm long) from three plants were collected from the field for use in detached leaf assay. The terminal branches were inserted into 35 agar-agar as a substratum in 250 ml plastic cups. Ten neonate larvae of *H. armigera* were released on the chickpea branches in each cup. The cups were kept under laboratory conditions at  $27 \pm 2^{\circ}\text{C}$ , and  $65 \pm 5\%$  RH. Data were recorded on leaf feeding (1 =<10% leaf area damaged, and 9 =>80% leaf area damaged). Data were also recorded on larval survival and larval weights. Leaf feeding scores in the test material ranged from 1.3 to 8.0 compared to 5.3 in the resistant check, ICC 506, and 6.3 to 7.0 in KAK 2. Larval survival was 53.3 to 100% in the test material, 90% on ICC 506, 76.7 to 80% on KAK 2. Weights of the surviving larvae ranged from 3.38 to 11.54 mg on test material, 6.93 mg on ICC 506, and 5.99 to 8.52 mg on KAK 2. The results suggested that there is considerable variation in the reference collection for resistance/susceptibility to the pod borer, *H. armigera*.

HC Sharma, MK Dhillon and HD Upadhyaya

**Confirmation of resistance of germplasm lines for ascochyta blight, botrytis gray mold, dry root rot, collar rot and Fusarium wilt in chickpea:** Three accessions ICCs 1915, 6306, 11284 that were found moderately resistant to Ascochyta blight (AB) in the preliminary evaluation were reevaluated for confirmation of their resistance under controlled environment following standardized evaluation technique. All the three entries were reconfirmed moderately resistant (3.1 to 5 rating on 1-9 rating scale) to AB. Similarly 55 moderately resistant (3.1 to 5 rating on 1-9 rating scale) accessions (33 kabulis, 17 desi, 5 intermediate types) to botrytis gray mold (BGM) were reevaluated for confirmation of resistance in controlled environment and all the 55 accessions again showed moderately resistant reaction. Of the 46 accessions found resistant to Fusarium wilt in the preliminary evaluation in wilt sick plot at ICRISAT, 21 were found asymptomatic and 25 had resistant reaction (<10% incidence) in glasshouse following standardized root dip technique. All the six moderately resistant accessions to dry root rot (DRR), ICC 1710, ICC 2242 (desi type), ICC 2277, ICC 11764, ICC 12328, and ICC 13441 (Kabuli type) were reconfirmed as moderately resistant (3.1 to 5 rating on 1-9 rating scale) using standardized blotter paper technique under laboratory conditions.

**Multiple disease resistance in chickpea germplasm accessions:** During reevaluation of new germplasm accessions, no line was found resistant or moderately resistant to more than two diseases. However, ICC 11284 (desi type) was the only accession with moderate level of resistance (3.1 to 5 rating on 1-9 rating scale) to both AB and BGM diseases. Combined resistance to AB and soil borne diseases particularly wilt, DRR, and collar rot was not recorded in any of the accessions tested. Two accessions, ICC 11764 and ICC 12328 had a moderate level of resistance (3.1 to 5 rating on 1-9 rating scale) to both BGM and DRR. Combined resistance to FW (<10% incidence) and BGM (3.1 to 5 rating) was found in 11 accessions. Four accessions, ICC 1710, ICC 2242, ICC 2277 and ICC 13441 had a combined resistance to both FW (11 to 20% incidences) and DRR (3.1 to 5 rating on 1-9 scale).

S Pande, M Sharma, HD Upadhyaya and CLL Gowda

**Confirmation of resistance for Fusarium wilt and sterility mosaic in germplasm accessions of pigeonpea:**

Twenty-eight wilt and sterility mosaic (SM) promising germplasm selections identified in the preliminary evaluation were retested for confirmation of resistance to both these diseases in wilt and SM sick plot under artificial epiphytotic conditions following standard field evaluation techniques at ICRISAT-Patancheru. Chopped wilted pigeonpea plants were incorporated every year in the sick plot to maintain threshold level of wilt fungus, *Fusarium udum*. For successful SM infection, each plant of test entries was leaf inoculated with SM infested leaves using leaf staple technique at two-leaf stage. Susceptible cultivars ICP 2376 for wilt (resistant to SM) and ICP 8863 for SM (resistant to wilt) were planted along with test material, after every ten test rows as indicator rows. Of the 28 accessions, two ICPs 11015 and 14819 had combined resistance to both wilt and SM diseases. Seven accessions, ICPs 7869, 8152, 9045, 11230, 11910, 13167, 13304 were found asymptomatic (0%) and 13 accessions, ICPs 6739, 8152, 9045, 11230, 11281, 11320, 11823, 13304, 13579, 14368, 14801, 14976, 15049 were found resistant (<10%) to SM.

S Pande, M Sharma, HD Upadhyaya and CLL Gowda

**Evaluation of groundnut germplasm for insect pests and bud necrosis disease:** A total of 2706 groundnut germplasm accessions were evaluated for resistance to foliar pests and agronomic characters related to pod yield during 2006-07 post-rainy season. Defoliation % due to insect/pest infestation and occurrence of Bud Necrosis Disease (BND) was recorded at crop maturity stage. BND ranged from 0% to 35% and defoliation from 1% to 25%. We identified 62 germplasm accessions resistant to BND (0%) and defoliation (1%) in comparison to BND in control cultivars M 13 (0%), Gangapuri (9%), ICGS 44 (14%), and ICGS 76 (9%) and defoliation in M 13 (5%), Gangapuri (15%), ICGS 44 (10%), and ICGS 76 (3%). Among the resistant accessions, ICGs 2773, 3053 and 4389 produced higher pod yield than all the four control cultivars.

GV Ranga Rao, HD Upadhyaya and CLL Gowda

*Milestone: A.3.1.4: Vegetable type pigeonpea germplasm evaluated for agronomic performance (HDU/CLLG, 2008)*

Based on pod and seed traits, we selected 105 vegetable type pigeonpea accessions from the entire collection for further verification and evaluation to identify best vegetable type pigeonpea accessions, which can enhance the income and nutrition of the poor. The trial was planted in 2007 rainy season. Recording of observations is in progress.

HD Upadhyaya and CLL Gowda

**Output target A.4: Germplasm accessions regenerated for conservation and distribution (2009)****Activity A.4.1: Regenerate critical accessions of staple crops germplasm**

*Milestone: A.4.1.1: Germplasm accessions of staple crops germplasm with low seed stock/viability regenerated (HDU, Annual)*

We secured seed samples of about 5700 accessions of different crops grown for regeneration during 2006. This year, we planted a total of 6426 accessions of different staple crops germplasm for replenishing seed stocks for medium-term, long-term and safety back-up storages. The total includes chickpea (1645), groundnut (2221), pearl millet (740), pigeonpea (320) and sorghum (1500). In addition, a total of 310 critical accessions representing chickpea (35), pigeonpea (12) and groundnut (260 including 130 wild relatives) were grown for regeneration in special facilities.

HD Upadhyaya

*Milestone: A.4.1.2: Seed viability and health of new and regenerated germplasm tested and viability of conserved germplasm monitored (HDU/RPT-PQL, Annual)*

During this year, we tested the seed viability of 8116 accessions. This included 1647 (sorghum-598; pearl millet-112; and chickpea-937) critical accessions regenerated for active collection and 3,461 (pearl millet-1527; and groundnut-1934) accessions multiplied for base collection. The mean seed viability of accessions for active collection was 94.6%, 96.7% and 98.8% for sorghum, pearl millet and chickpea, respectively. Germplasm seed samples with viability above 85% were processed as base collection and the mean seed viability of germplasm ranged from 94.5% for pearl millet to 96.0% for groundnut.

An inventory on seed viability of active collections (2416 accessions) comprising of chickpea (1934) and sorghum (482) was conducted. The viability ranged between 21-100% for sorghum with a mean of 95.0% and 68-100% for chickpea with a mean of 97.9%. Seed viability testing also included monitoring viability of 1676 accessions (sorghum-882 and pearl millet-794) conserved as base collection for over 10 years. The seed viability of sorghum accessions ranged between 74-100% with a mean of 95.9%, and pearl millet accessions from 48-100% with a mean of 93.5%. We identified 12 accessions of sorghum and 83 accessions of pearl millet with viability <85% for regeneration.

HD Upadhyaya and RP Thakur

A systematic seed health testing of germplasm is critical for their medium- and long-term conservation without affecting seed viability by seedborne pathogens. A total of 2084 germplasm accessions (sorghum-300, chickpea-309 and groundnut-1475) regenerated from the medium term storage of the genebank were evaluated for their seed health status using the standard blotter method. Eighty-one of 1784 accessions were free from seedborne pathogens (chickpea-24 and groundnut-57). We detected 18 fungi in chickpea and 19 in groundnut. Major fungi detected both in chickpea and groundnut were species of *Aspergillus*, *Fusarium* and *Rhizopus*. Species of *Cladosporium* and *Alternaria* were specific to chickpea, while *Rhizoctonia* and *Penicillium* were specific to groundnut. In chickpea, 35 accessions and in groundnut, 11 accessions had <80% germination and >80% infection by these fungi. Effective seed treatment procedures will be developed to control these fungi.

RP Thakur and HD Upadhyaya

*Milestone: A.4.1.3: Germplasm samples processed for medium- and long-term conservation (HDU, Annual)*

A total of 6388 freshly harvested germplasm seed samples of different crops have been transferred to the cold rooms following standard protocols. This included 3773 (sorghum-1080, pearl millet-112 and chickpea-2581) accessions as active collection and 2615 (pearl millet-684 and groundnut-1931) accessions as base collection. With this addition, the total number of accessions as base collection increased to 103,818 accessions representing 87.3% of total collection. Processing of about 2500 accessions representing sorghum, pigeonpea and groundnut from 2006 planting seasons is in progress.

The influence of seed size in chickpea on moisture content during drying and the impact of drying on seed viability were studied using 30 accessions, representing small, medium and large sizes. Differences in seed moisture contents under constant drying environment were significant among the three seed sizes. Larger seeds lost moisture relatively rapidly and the seeds attained constant weights at 28 days after the start of drying cycle with no appreciable loss at 35 days after the start of drying. Large seeds show lowest equilibrium moisture content compared to medium and small sized seeds throughout the drying period. Lower equilibrium moisture content in larger seeds was seemingly affected by the nature and the thickness of seed coat that helps in efficient and cost-effective planning for seed drying.

We also studied the viability of groundnut seeds under a range of storage conditions. The results have demonstrated potential benefit of storing groundnut seeds with very low moisture levels (ultra-dry storage). Groundnut seeds dried to up to 4% moisture content retained viability considerably longer periods and replacing air with vacuum further enhanced seed longevity. Seeds dried to very low moisture content (1.7%) retained higher viability levels for over two years of storage at 50°C. Ultra dry storage of groundnut seed improves longevity and valuable germplasm or breeding samples can be safely dried and stored for longer periods even under ambient conditions saving on refrigerated storage and frequent regeneration.

HD Upadhyaya

#### **Activity A.4.2: Establish safety back up collections of staple crops**

*Milestone: A.4.2.1: Facilities identified for backup safety storage of germplasm collections in collaboration with partners and samples processed for safety backup (HDU/CLLG, Annual)*

During this year, we prepared seed samples of 3052 sorghum accessions following standard protocols. We have prepared a 5-year plan for transferring about 111,000 accessions of different crops as safety back-up collection at Global Seed Vault at Svalbard, Norway. Seed samples of 20,000 accessions are under preparation for transfer during January 2008.

HD Upadhyaya and CLL Gowda

***Output target A.5: Germplasm databases updated for utilization (2009)***

**Activity A.5.1: Update databases of staple crops germplasm**

*Milestone A.5.1.1: Gaps in germplasm characterization data filled for chickpea, pigeonpea and groundnut (HDU/CLLG/Scientists - Crop Improvement, 2008)*

Documentation of characterization data on 3505 accessions grown during 2006 is in progress. This includes data on 486 accessions of chickpea, 866 accessions of pigeonpea and 1671 accessions of groundnut.

HD Upadhyaya and CLL Gowda

*Milestone A.5.1.2: Passport and characterization databases of sorghum and pearl millet germplasm updated (HDU, 2009)*

Germplasm databases on passport information for 1130 sorghum accessions (528 accessions from ICRISAT, Niger and 602 from USDA, USA) and 953 chickpea accessions (252 from ICARDA, Syria and 701 from USDA, USA) has been documented and updated. Characterization data for sorghum on 614 accessions for 22 descriptors (post-rainy) and 385 accessions for two descriptors (rainy) and pearl millet on 3026 accessions for 21 descriptors has been updated.

HD Upadhyaya and CLL Gowda

*Milestone A.5.1.3: Germplasm databases of staple crops updated to SINGER format (HDU, 2009)*

Germplasm databases on passport information, characterization and distribution are being checked for completeness for SINGER format.

HD Upadhyaya

***Output target A.6: Germplasm of staple crops assembled and conserved for utilization at Regional Genebanks in Africa (2010)***

**Activity A.6.1: Identify sorghum collection gaps, collect and conserve new germplasm from identified priority areas in the eastern and southern Africa (ESA)**

*Milestone A.6.1.1: Gaps in sorghum germplasm collection identified, germplasm collected from at least 3 ESA countries and conserved (MAM/SGM, 2008)*

No report for 2007.

*Milestone A.6.1.2: Wild and cultivated sorghums collected in at least 40 locations across Kenya assembled. Collection report completed and delivered to NARS partners in Kenya (SdV/FS/NARS/University of Free State/University of Hohenheim, 2007)*

A total of 354 samples of cultivated (223 accessions) and wild (131 accessions) sorghums were assembled from 148 locations in the main cultivation areas of Eastern, Western, Northern Rift valley (Turkana) and Coastal Kenya. Of these, 42 accessions of wild sorghum that were collected from the coast were submitted to the genebank of Kenya for long-term conservation. This contributed 78% of the coastal wild sorghum collections in the gene bank and covered at least 5 new districts. The remainder of the material is currently undergoing multiplication and morphological characterization in preparation for submission to the genebank for conservation.

S de Villiers, F Sagnard, NARS, University of Free State and University of Hohenheim

**Activity A.6.2: Safely conserve assembled germplasm for utilization**

*Milestone: A.6.2.1: Germination tested for groundnut, sorghum and millet germplasm accessions at Sadore, Niger (BH, Annual)*

Germination percentage was determined for a total of 2670 groundnut and 207 sorghum accessions at Sadore in 2007, and critical accessions were identified for regeneration.

BIG Haussman

*Milestone: A.6.2.2: Critical accessions of groundnut, sorghum and millet regenerated in glasshouses at Sadore, Niger (BH, Annual)*

Thirty-five critical groundnut accessions were regenerated in the glasshouse at Sadore in 2007.

BIG Haussman

*Milestone: A.6.2.3: Germplasm accessions of groundnut, sorghum and pearl millet regenerated in the field at Sadore, Niger (BH, Annual)*

Regeneration activities at Sadore in the 2007 rainy season included 1550 groundnut and 207 sorghum accessions.

BIG Haussman

### **Activity A.6.3: Conserve safety copy of germplasm held at ICRISAT, Patancheru at Sadore, Niger**

*Milestone A.6.3.1: Safety copy of germplasm conserved at Niamey genebank (groundnut, finger millet and pearl millet) (BH, Annual)*

The safety duplication conserved in the genebank at Sadore currently comprises 5205 pearl millet, 7622 finger millet and 2006 groundnut accessions obtained from ICRISAT-Patancheru.

BIG Haussman

### **Activity A.6.4: Upgrade an ESA regional short-term seed storage facility in Kiboko**

*Milestone A.6.4.1: Short-term seed storage facility renovated and modules purchased and installed (MAM/SGM, 2007)*

Completed and reported in 2006.

### **Activity A.6.5: Develop strategy for better documentation of germplasm accessions at Sadore genebank**

*Milestone A.6.5.1: Strategic plan for documentation of germplasm developed and implemented (BH, 2008)*

We have started developing an electronic catalogue of accessions held in the Sadore genebank and it is planned to have a M.Sc. student from Hohenheim University working on this in early 2008.

BIG Haussman

### **Output target A.7: Unrestricted access and movement for staple crops germplasm ensured (2009)**

#### **Activity A.7.1: Assure risk-free export and import of germplasm materials**

*Milestone A.7.1.1: Requested germplasm of staple crops distributed to bona fide users for utilization (RPT/HDU/NBPGR/BH/MGM, Annual)*

During this year, we distributed a total of 1886 samples of staple crops germplasm (sorghum-521; pearl millet-34 chickpea-944; pigeonpea- 270; and groundnut-117) for utilization to scientists in 16 countries in 70 consignments following standard protocols. Some of the special requests for germplasm include mini-core sets of chickpea and groundnut for collaborative evaluation with NARS in India and sorghum in USA. Additionally, we provided 6669 samples of germplasm for internal utilization. The total includes sorghum-1106, pearl millet-649, chickpea-2915, pigeonpea-1330 and groundnut-3273.

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A total of 27 groundnut, one sorghum and two pearl millet samples were distributed by the Sadore genebank in 2007. Further, breeding materials were also distributed by the respective pearl millet and sorghum breeding programs in the region.

BIG Haussman

*Milestone A.7.1.2: Requested germplasm of staple crops exported for utilization and new germplasm imported for conservation after seed health evaluation and clearance through NBPGR (RPT/HDU/NBPGR, Annual)*

Requested germplasm of staple crops exported for utilization and new germplasm imported for conservation after seed health evaluation and clearance through NBPGR (RPT/HDU/NBPGR, Annual)

**Export of staple crops:** We processed and successfully exported 8602 seed samples (sorghum-4107, pearl millet-785, chickpea-3226, pigeonpea-101 and groundnut-383) comprising of breeding lines and germplasm accessions to 35 countries with 84 phytosanitary certificates. Seventy-three (sorghum-21, pearl millet-11, chickpea-38, and pigeonpea-3) were rejected due to poor germination and/or association of seedborne fungi (*Acrimonium* species, *Bipolaris setariae*, *Gleocercospora sorghi*, *Fusarium oxysporum* f.sp. ciceri, *F. udum* & *Rhizoctonia* species), or infested with store grain pest or bacterium-contaminated seed.

**Bulk export of seed material:** A bulk consignment of 71 kg pearl millet variety seed of Raj-171 was exported to Dubai. The phytosanitary clearance for this consignment was obtained from the Directorate of Plant Protection, Quarantine and Storage (DPPQS), Hyderabad.

**Import of germplasm of staple crops:** We imported 1492 germplasm samples of 865 sorghum (USA 21 and Kenya 844), 226 chickpea (Syria 19, Ukraine 72, Israel 17 and Australia 118), 13 groundnut (Indonesia 3, Brazil 1 and Vietnam 9), and 303 maize from Mexico. Sorghum from Kenya was for nutritional analysis and released as such. Sorghum from USA and chickpea from Ukraine and Australia were planted in PEQIA for inspection of exotic pests and release by NBPGR. In addition, 303 maize accessions from Mexico imported by Dr CT Hash and 7 maize accessions imported by SM Sehgal Foundation from Vietnam will be planted in PEQIA for inspection and release by NBPGR. The remaining consignments (chickpea from Syria, Israel and all groundnut consignments) were grown in Plant quarantine glasshouse facility and inspected for exotic pests. As all were found free from exotic pests they were released to concerned scientists.

**Import of soil and plant material:** Through special import permit obtained from Directorate of Plant Protection, Quarantine and Storage (DPPQS), Faridabad we imported 414 dried and powdered samples of maize stover (300) and pigeonpea stover (88) from Ethiopia, vegetable stover (26) from Pakistan for ILRI-ICRISAT, and 109 soil samples from Pakistan for IWMI. All these samples were required for various nutritional and chemical analyses.

RP Thakur, HD Upadhyaya and NBPGR

## **Output B: Germplasm of six small millets assembled and conserved germplasm characterized/ evaluated and documented for utilization and knowledge shared with partners**

### **Summary**

*During 2007, we assembled from Tamil Nadu Agricultural University (TNAU) 43 samples of six small millets germplasm collected in Tamil Nadu, India for conservation and utilization and made formal requests for securing 200 foxtail millet accessions from Chinese Academy of Agricultural Sciences (CAAS), China.*

*The finger millet composite collection (1000 accessions), and mini-core (65 accessions) were grown for agronomic characterization and for evaluation of yield (40) and forage (20). We characterized 500 accessions of foxtail millet for important morpho-agronomic characters and evaluated 40 accessions for yield. We planted 1673 accessions (finger millet – 1126 and foxtail millet – 547) for seed regeneration and processed 147 seed samples for conservation. Characterization details for 1000 accessions of finger millet on important qualitative and quantitative traits have been documented. Sets of finger millet (60) and foxtail millet (40) accessions were evaluated for useful traits and several sources identified for agronomic yield and forage use.*

*Seed samples of 3042 accessions comprising of barnyard millet (479), foxtail millet (1039), kodo millet (628), little millet (375) and proso millet (521) have been processed for safety back-up at the Regional Genebank, ICRISAT- Niamey Center.*

*During 2007, we supplied 337 samples of germplasm (finger millet 134, foxtail millet 188, proso millet 5, kodo millet 5 and barnyard millet 15) to scientists for utilization in crop improvement programs in three countries.*

**Output target B.1: New germplasm of small millets assembled for conservation and utilization (2009)**

**Activity B.1.1: Identify gaps and priority areas for germplasm of six small millets**

*Milestone B.1.1.1: Global databases of finger millet compared to identify missing unique germplasm, and priority areas identified for finger millet for collection/assembly in collaboration with NARS (CLLG/HDU/NARS scientists, 2007)*

The finger millet germplasm databases of the national collection in Kenya and ICRISAT-Niamey were compared with that of ICRISAT-Patancheru to identify unique germplasm. We corresponded with the Tamil Nadu Agricultural University (TNAU), Coimbatore, on recently collected finger millet germplasm accessions. We secured from the TNAU seven samples collected in Tamil Nadu, India for conservation and utilization. We have identified some of the national collections in India, Kenya, Tanzania and Uganda as unique for comparison of databases for identifying the unique accessions for filling gaps in ICRISAT collection. Contacts with some of the NARS in these countries eg, University of Agricultural Sciences, Bangalore, Acharya N G Ranga Agricultural University, Hyderabad and Rajendra Agricultural University, Muzaffarpur in India, National Agricultural Research Organization, Uganda, Kenya Agricultural Research Institute, Kenya and Department of Research and Development, Tanzania were established for identifying unique germplasm for future assembly and filling the gaps in our collection.

CLL Gowda and HD Upadhyaya

*Milestone B.1.1.2: Global databases of foxtail millet, little millet, kodo millet, proso millet and barnyard millet compared to identify unique germplasm (CLLG/HDU/NARS scientists, 2008)*

Finger millet is an important crop in several countries of Asia and East Africa. The germplasm collection at ICRISAT represents 5949 accessions from 24 countries. However, gaps exist in the collection for some important morphoagronomic traits especially extra-early and very late-maturing types, tall types for fodder use and most desirable white grain types. The races representing *elongata* and *compacta* (cultivated) and race *Africana* and *spontania* (wild types) are poorly represented in the collection. Also, some of the geographical regions were not covered or poorly represented in the existing collection. Priority areas identified for collections include Burundi, Ethiopia (centre of origin), India, Kenya, Malawi, Nepal, Rwanda, southern Sudan, Tanzania, Uganda, Zaire and Zambia. We have identified NARS in some of the countries like India, and countries in East Africa (Kenya, Tanzania and Uganda) for enhancing this activity.

CLL Gowda and HD Upadhyaya

*Milestone B.1.1.3: Priorities areas identified for foxtail millet, little millet, kodo millet, proso millet and barnyard millet for collection/assembly in collaboration with NARS (CLLG/HDU, 2009)*

We assembled from Tamil Nadu Agricultural University (TNAU) six germplasm samples each of foxtail millet, little millet, kodo millet, proso millet and barnyard millet collected in Tamil Nadu, India for conservation and utilization.

CLL Gowda and HD Upadhyaya

**Output target B.2: Assembled germplasm characterized and evaluated for economic traits for utilization (2009)**

**Activity B.2.1: Characterize new germplasm/data missing accessions of six small millets for morpho-agronomic traits**

*Milestone B.2.2.1: New germplasm of finger millet characterized for economic traits (CLLG/HDU, 2008)*

We planted 1000 accessions of finger millet composite collection and 65 finger millet mini-core collection accessions for characterization for important morpho-agronomic characters like days to 50% flowering, plant height, inflorescence length and width, race and subraces. In addition, we evaluated 40 accessions for yield, and 20 accessions for forage. We have collected field data and identified several promising sources for yield and forage use. Documentation of post-harvest data is in progress.

A Bharathi, CLL Gowda and HD Upadhyaya

*Milestone B.2.2.2: Germplasm of foxtail millet, little millet, kodo millet, proso millet and barnyard millet characterized (CLLG/HDU, 2009)*

We grew 500 accessions of foxtail millet composite collection for characterization for important morpho-agronomic characters like days to 50% flowering, plant height, inflorescence length and width, race and subraces. Additionally, we evaluated 40 accessions for yield. Documentation of post-harvest data is in progress.

A Bharathi, CLL Gowda and HD Upadhyaya

**Output target B.3: Germplasm accessions regenerated for conservation and distribution (2009)**

**Activity B.3.1: Regenerate critical accessions of small millets germplasm**

*Milestone B.3.1.1: Germplasm accessions of small millets with limited seed stock/viability regenerated and seed samples processed for medium- and long-term conservation (HDU, Annual)*

During the year, we planted 1673 accessions of finger millet (1126) and foxtail millet (547) for regeneration. This includes germplasm composite sets of finger millet (1000 accessions) and foxtail millet (500 accessions). We processed the seed samples of 147 accessions regenerated during 2006 to medium-term cold rooms.

HD Upadhyaya

*Milestone B.3.1.2: Seed viability and health of new and regenerated small millets germplasm tested and viability of conserved germplasm monitored (HDU/RPT, Annual)*

Tested seed viability of 122 accessions of finger millet (15), foxtail millet (46), barnyard millet (42), little millet (2) and proso millet (17).

**Field monitoring of regenerated small millets:** Finger millet (1125) and foxtail millet (540) germplasm accessions regenerated by genebank during kharif 2007 in the field RCE 23N were monitored during the active growth period for the plant health. All foxtail millet accessions were found healthy. In finger millet, 15 of 1125 accessions (IE 501, IE 633, IE 2293, IE 2322, IE 2384, IE 2589, IE 2622, IE 5960, IE 4005, IE 5875, IE 4491, IE 2957, IE 5367, IE 860, IE 2811) were found infected with blast disease caused by *Magnaporthe grisea* (Hebert) Barr [teleomorph] and accessions IE 5367, IE 860 and IE 2811 were observed as highly susceptible for blast. The pathogen was isolated, purified and cultured to study the seedborne nature and to develop screening technique. Seed viability and seed health testing of these regenerated germplasm accessions will be conducted after post-harvest operations.

RP Thakur and HD Upadhyaya

*Milestone B.3.1.3: Small millets germplasm processed for safety back up (CLLG/HDU/BH, Annual)*

Duplicate conservation is required to ensure the safety of the assembled germplasm against possible disasters. Seed samples of 3042 accessions comprising of barnyard millet (479), foxtail millet (1039), kodo millet (628), little millet (375) and proso millet (521) have been processed for safety back-up (for preservation at -20°C) at the Regional Genebank, ICRISAT-Niamey Center. A safety backup of 7622 finger millet samples is currently conserved at the Sadore genebank.

CLL Gowda, HD Upadhyaya and BIG Haussman

**Output target B.4: Unrestricted access and movement for small millets germplasm ensured (2009)**

**Activity B.4.1: Assure risk-free export and import of small millets germplasm materials**

*Milestone B.4.1.1: Requested germplasm of small millets distributed to bona fide users for utilization (RPT/HDU/NBPGR, Annual)*

During 2007, we distributed a total of 337 samples of small millets germplasm (finger millet-134, foxtail millet-188, proso millet-5, kodo millet-5 and barnyard millet-5) for utilization to scientists in three countries. The finger millet germplasm distribution includes mini-core accessions of finger millet to USA and Australia and



foxtail millet core collection to USA. Additionally, we provided 229 samples of germplasm for internal utilization. The total includes finger millet-146 foxtail millet-63, proso millet-5, little millet-4, kodo millet-3 and barnyard millet-8.

RP Thakur, HD Upadhyaya and NBPGR

*Milestone B.4.1.2: Requested germplasm of small millets exported for utilization and new germplasm imported for conservation after seed health evaluation and clearance through NBPGR (RPT/HDU/NBPGR, Annual)*

**Export of small millets:** A total of 281 small millets (foxtail millet (152) to USA and finger millet (60) to Australia and (69) to USA) were exported to Australia and USA under 3 phytosanitary certificates. No small millets were imported during this year.

RP Thakur, HD Upadhyaya and NBPGR

***Output target B.5: Germplasm of small millets assembled and conserved for utilization at Regional Genebanks in Africa (2009)***

**Activity B.5.1: Identify collection gaps for finger millet in ESA and conduct collection mission to fill gaps**

*Milestone B.5.1.1: Gaps in finger millet collection identified and filled in at least 2 countries in ESA (MAM/SGM, 2009)*

No report for 2007

**Activity B.5.2: Facilities improved at ICRISAT Niamey genebank for safety back up collections of small millets**

*Milestone B.5.2.1: Storage facilities for the safety back up of small millet collections improved at Niamey, Niger (BH/HDU/CLLG, 2007)*

The World Bank funded GPG1 Project supported improving the physical infrastructure, including deep freezers for the safety backup of pearl millet, six small millets and groundnut germplasm conserved at Rajendra S Paroda Genebank, Patancheru, India. We acquired a total of 20 deep freezers for conserving the germplasm material sets from Patancheru. Necessary modifications have been made for accomplishing this task. The deep freezers room of the Sadore genebank has been upgraded with two air conditioners (each 5HP) and power stabilizers for the deep freezers. Furthermore, the gangway to the plant and soil lab has been closed to reduce dust entering the deep freezers room, and safety lights were installed.

BIG Haussman

***Output target B.6: Databases of small millets germplasm updated for utilization (2010)***

**Activity B.6.1: Update germplasm databases of small millets**

*Milestone B.6.1.1: Passport, characterization and evaluation data of small millets germplasm documented (HDU, 2007)*

We documented the qualitative and quantitative characters on 1000 accessions of finger millet germplasm as per IBPGR descriptors. The qualitative characters include plant pigmentation, growth habit, inflorescence compactness, glume prominence, fruit color, subspecies, race, subrace, overall plant aspect, and lodging. The quantitative characters are plant height, basal tillers number, culm branching number, days to flowering, flag left blade length, flag leaf blade width, flag leaf sheath length, peduncle length, panicle exertion, inflorescence length, inflorescence width, longest finger length, longest finger width and panicle branches number.

HD Upadhyaya

*Milestone B.6.1.2: Gaps in germplasm characterization data filled for small millets (HDU, 2008)*

Characterization data on 13 accessions of different crops have been updated.

HD Upadhyaya

*Milestone B.6.1.3: Germplasm databases of small millets updated to SINGER format (HDU/CLLG, 2009)*

Germplasm databases on passport information, characterization and distribution are being updated for completeness for SINGER format.

HD Upadhyaya

**Output C: Core and mini-core collections, and trait specific germplasm identified and evaluated for utilization; composite sets and reference collections established and genotyped to assess genetic diversity and population structure; and made available to partners annually on request; data capture, storage and analysis through appropriate management systems and dissemination through databases and web services**

### Summary

*During 2007, we established pearl millet core collection (2094 accessions) by augmenting the earlier core collection (1600 accessions) representing germplasm from 46 countries. The sorghum core collection (2246 accessions) was evaluated for 11 morphological and 10 agronomic traits to estimate phenotypic diversity. This set provides a sample of sorghum genetic diversity for use in breeding programs and information for developing the mini-core collection.*

*The finger millet core collection (622 accessions) was evaluated for five qualitative and 15 quantitative traits to determine phenotypic diversity and identify accessions for economic traits and development of mini-core collection. The foxtail millet collection has been stratified according to geographical regions and taxonomic races and data analyzed for developing core subset. The composite collections of pigeonpea, pearl millet and finger millet (1000 accessions each) and foxtail millet (500 accessions) were constituted using phenotypic characterization data, geographical origin and taxonomy.*

*The population structure of chickpea (3000 accessions, 50 SSRs), sorghum (3367 accessions, 41 SSRs), groundnut (1000 accessions, 21 SSRs), pigeonpea (1000 accessions, 20 SSRs) and finger millet (1000 accessions, 20 SSRs) was determined. In all the crops, wild types clustered separately. In chickpea, desi and kabuli types and in groundnut, fastigiata and hypogaea types, clustered separately. In sorghum, landrace population and wild accession substructure was further characterized within racial groups (five basic races and ten hybrid races). Race bicolor showed little evidence of population structure, congruent with it being the original domesticate. Reference sets consisting of most diverse 384 accessions in sorghum, and 300 accessions each in chickpea, groundnut, pigeonpea, and finger millet have been established.*

*ICRISAT produced 105,000 (3000 x 35) data points and ICARDA produced 45,000 (3000 x 15) data points on the chickpea composite collection. Combined together 150,000 data points were generated. After quality assessment 145,750 (2915 x 50) data points were validated for final contribution to the GCP data repository. Similarly, in groundnut after quality assessment 17,892 (852 X 21) data points were validated for final contribution to the GCP data repository.*

*In foxtail millet, DNA was extracted from composite collection (500 accessions). Since no SSR markers were available in the public domain, 48 markers from pearl millet and 31 markers from finger millet are being screened with 8 diverse genotypes and 10 markers have been identified as polymorphic. Genotyping has started with 10 markers and an additional unpublished 30 EST SSR markers from pearl millet screened, with 10 showing good transferability to foxtail millet.*

*In ESA, NARS subsets between 164 and 298 accessions per country have been used for phenotyping sorghum germplasm. These comprise landraces, farmer varieties, improved cultivars and breeding lines. A total of 1544 accessions have been phenotyped in at least one site. Seven countries have been supplied with computer hardware and software to enhance phenotyping data documentation and retrieval.*

*The PCR conditions for 40 SSR markers have been optimized at the BecA lab in Nairobi, Kenya and used for genotyping of 886 accessions from Tanzania, Kenya, Eritrea, Burundi and Rwanda resulting in 355,440 data points. Data analysis for 200 accessions from Tanzania has been completed while the analysis for materials from the other countries is in progress to determine the diversity and genetic relations within and between the countries.*

*Our NARS partners evaluated the mini-core of pigeonpea (146 accessions) at Bangalore, Dholi, Dantiwada, Jalna, Kanpur and Khargone; groundnut (184 accessions) at Durgapura and Raichur; finger millet (65 accessions) at Kolhapur; and pearl millet (504 accessions) at Mandor, Durgapura, and Jamnagar, India and identified several promising sources for utilization in the crop improvement.*

*The mini-core collections were also evaluated for resistance to various biotic and abiotic stresses to identify new sources of resistance in chickpea for ascochyta blight and botrytis gray mold at Punjab Agricultural University (PAU), Ludhiana; pigeonpea for combined resistance to fusarium wilt and sterility mosaic and for resistance to pod borer, *H. armigera*; and in groundnut for *A. flavus* seed infection; and in sorghum for grain mold at Patancheru. Sources of resistance to groundnut rosette disease and early leaf spot were identified at Chitedze Research Station, Malawi. For abiotic stresses new sources were identified in chickpea, groundnut and pigeonpea for salinity tolerance and for transpiration efficiency in groundnut.*

*The response of mapping population parents E 36-1, PB 15881-3, BTX 623 and IS 18551 have been confirmed for salt-tolerance in relation to the performance of IS 9830, N13, PB 15520 and B 35.*

*A part of the global pearl millet core collection (504 accessions) was characterized at ICRISAT-Sadore (Niger) for 6 qualitative and 21 quantitative traits. The study revealed large variation for nearly all traits, indicating the potential of the core collection to provide source materials for broadening the genetic base of breeding populations.*

*Finger millet core collection accessions from Africa (Kenya-55, Malawi-24, Nigeria-5, Uganda-70, Zambia-18, Zimbabwe-88), Asia (India-147, Nepal-66), Europe (Italy-3, UK-3) and USA (5) were evaluated for 15 quantitative traits at Alupe and Kiboko in Kenya in 2005 and 2006 to discern the variability in this germplasm.*

*For broadening the genetic base in groundnut and pigeonpea, interspecific hybrids were provided using A and B genome species in groundnut and *Cajanus platycarpus* and *C. cajan* in pigeonpea.*

*The LIMS database at Patancheru in 2007 has been used for the acquisition of genotyping data from groundnut (922 accessions), sorghum (3398 accessions), finger millet (1003 accessions), and is currently being used to acquire genotyping data from mapping populations in chickpea, pigeonpea, pearl millet and groundnut.*

*The Integrated ICRISAT Crop Resources Information System (ICRIS) has been enhanced with a PostgreSQL database backend to store genotype and phenotype data of ICRISAT mandate crops. The database currently stores a small number of genotype datasets of chickpea and sorghum, and phenotype datasets of pearl millet, groundnut and chickpea.*

*The iMAS system has been extensively refined based on user feedback received from the International iMAS Testing Workshop held in May 2007 at ICRISAT, Patancheru. Version 1.0 of the system was released and is available on CD or for download from ICRISAT Internet web site. The pipelines and standalone software available within the comparative genomics and population genetics toolboxes on the high performance computer have been in use during 2007.*

*Output C: Core and mini-core collections, and trait specific germplasm identified and evaluated for utilization; composite sets and reference collections established and genotyped to assess genetic diversity and population structure; and made available to partners annually on request*

#### **Outcome:**

Researchers from public sector institutions in 11 countries of Asia, Africa and North America have used recently mini core collections for screening in the selection of trait-specific germplasm. These researchers have opted to test the mini core due to its drastically reduced size (1% of entire collection compared with the core 10% collection), but still capturing about 80% of genetic diversity of the entire collection.

The mini core collection concept was postulated by ICRISAT scientists (Upadhyaya and Ortiz 2001, TAG 102:1292-1298). Following this approach a groundnut mini core collection was developed at Tifton, Georgia, USA (Holbrook and Dong 2005: Crop Sci. 45:1540-1544). Mini core collections are essentially used for identifying new sources of resistance/tolerance against various biotic and abiotic stresses and for selection of favourable agronomic traits. The selected accessions are used subsequently in crop improvement to incorporate selected traits into high and stable yielding backgrounds. For example, currently four graduate students are

pursuing research involving mini core collections for their Master's and Ph D degrees at the University of Agricultural Sciences (UAS), Dharwad; Tamil Nadu Agricultural University (TNAU), Coimbatore; and Osmania University, Hyderabad; India.

Mini core collections represent the basic germplasm used in research. These collections are of a size small enough to allow evaluation/screening of diverse germplasm to identify sources of economically important traits (such as resistance to biotic and abiotic stresses, etc.). Such value-added accessions are useful globally, wherever such traits are needed. The accessions from the core and even the entire collection can be examined selectively from the same cluster (s) from which the relevant sources in the mini core collection have been identified, using a reverse funnel approach, to select additional sources of resistance.

**Evidence for the outcome:** Owing to the convenient sample size of the mini core collections [242 sorghum (entire collection size is 22, 473 accessions), 211 chickpea (16, 991), 184 groundnut (14, 310), 146 pigeonpea (12, 153), and 65 finger millet (5, 940)], it was feasible to evaluate these subsets effectively in replicated trials and identify useful trait-specific germplasm. Publication of the mini core strategy helped in creating awareness of the usefulness of mini core collections. Germplasm of 53 mini core sets (22 each of chickpea and groundnut, 7 pigeonpea, and 1 each of sorghum and finger millet) were sent to researchers in 11 countries on their request over the last few years. They have identified several sources of high grain yield, high grain quality traits and resistance/tolerance to stress factors. To enumerate some of these; on the evaluation of the chickpea mini-core at Kanpur (India), four large seeded kabuli accessions (ICCs 12033, 14203, 14187 and 14199) were selected for use in their research of kabuli cultivar development (Kaul et al. 2005; Indian Journal of Plant Genetic Resources 18:201-204), and at Raipur (India), six superior accessions (ICCs 5879, 7255, 8350, 10393, 10885 and 13125) were identified for use in their on-going research (Johnson et al. 2007; NLS 2007, November 2007, IIPR, Kanpur). Groundnut mini-core testing at Dharwad (India), resulted in the discovery of two accessions (ICGs 8760 and 13787) with multiple resistance to late leaf spot, rust, and aflatoxin contamination (Kusuma et al. 2007; ISOR National Seminar, 29-31 January, 2007, Hyderabad, India). Similarly, evaluation of the groundnut mini core in south East Asian countries gave excellent results. For example, for high quality and greater oil contents and resistance to bacterial wilt, 11 and 14 accessions, respectively, were selected in China, for large seed size, 5 accessions each in China and Thailand, and for high shelling percentage, 5 accessions each in China, Thailand and Vietnam were selected. From the pigeonpea mini-core evaluation at Kanpur (India), 10 agronomic traits exhibited high diversity and the source-accessions were selected for use in research (Singh et al. 2007; NLS 2007, November 2007, IIPR, Kanpur). Evaluation of the pigeonpea mini core at the International Center for the Biosaline Agriculture, Dubai, United Arab Emirates, resulted in identification of a few notable accessions that performed very well under saline conditions and hold much promise for future research (Rao and Shahid 2007. Biosalinity News).

The mini core collections are also being proposed in pursuing new areas of research. For example, oligosaccharides cause flatulence in chickpea. Dr JN Kannan is pursuing molecular research at TNAU, Coimbatore, India to reduce this anti-nutritional trait using the chickpea mini core (Project summary). The Ministry of Science and Technology, Government of India in their letter (No. BT/AGR/ TF/2006 dt. 10 Jan 2008), has suggested that this research would benefit from material from ICRISAT. Similarly in grant proposals on association mapping for drought tolerance traits in groundnut by the UAS, Bangalore, India and in pigeonpea by NBPGR, New Delhi, India the mini core collections will be used.

#### **Activity C.1.1: Establish core and mini-core collections of staple crops and small millets**

*Milestone C.1.1.1: Mini-core subset of pigeonpea germplasm established (HDU/CLLG, 2006)*

**Augmenting pearl millet core collection:** Augmented the earlier core collection (1600 accessions) by adding the representative accessions (494) from the germplasm collection not considered earlier. The new pearl millet core collection consisting 2094 accessions representing 46 countries was planted during the 2007 rainy season for characterization. Recording of morpho-agronomic data is in progress to study pattern of diversity and develop the mini-core collection.

HD Upadhyaya and CLL Gowda

*Milestone C.1.1.2: Mini-core subset of sorghum established (HDU/CLLG, 2008)*

The sorghum [*Sorghum bicolor* (L.) Moench] core collection consists of 2246 accessions including all five basic races (*bicolor*, *guinea*, *caudatum*, *kafir*, and *durra*) and their ten intermediate races (*guinea-bicolor*, *guinea-*

*caudatum*, *guinea-kafir*, *guinea-durra*, *caudatum-bicolor*, *kafir-bicolor*, *durra-bicolor*, *kafir-caudatum*, *kafir-durra*, and *durra-caudatum*). This core collection was evaluated in a single short-daylength environment for 11 morphological and 10 agronomic traits to estimate phenotypic diversity. Polymorphism was observed for all observed morphological traits. Most accessions in the core collection had pigmented foliage, nodal tillers, white midribs, semi-loose stiff panicle branches, and lustrous grains half covered by glumes that were freely threshable, without seed subcoat, and having partly corneous endosperm texture. Variance due to genotypes was significant for all observed quantitative characters in the entire core collection and for plant height and panicle length in each of the basic and intermediate races individually. The basic and intermediate races differed significantly for means of all observed traits except panicle exertion, and plant and plot grain yields, and for variances of all the traits except plant grain yield. *Kafir-bicolor* accessions were earliest to flower and *guinea-bicolor* accessions were taller with high 100-grain weight. Estimates of broad sense heritability were high for time to 50% flowering, plant height, panicle exertion, panicle length, and panicle width. Phenotypic correlations among observed traits were significant. Those between time to 50% flowering and plant height in two basic and three intermediate races (0.712–0.855) and between grain yield per plant and grain yield per plot in two basic races and seven intermediate races (0.718–0.841) were large, accounting for >50% of observed variation. Principal component analysis showed that five agronomic traits (time to 50% flowering, plant height, 100-grain weight, grain yield per plant, and grain yield per plot) accounted for most of the variation between accessions in the entire core, and in most basic races and intermediate races, individually. Cluster analysis using Gower's dissimilarity resulted in to five race-based clusters. The accessions in this core provide a sample of sorghum genetic diversity that can be utilized readily in breeding programs for development of genetically diverse cultivars and development of sorghum mini-core collection.

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*Milestone C.1.1.3: Mini-core subset of finger millet established (HDU/CLLG, 2009)*

The finger millet core collection consisting of 622-accessions predominantly consisting of four cultivated races *vulgaris*, *plana*, *compacta*, and *elongata* was evaluated for five qualitative and 15 quantitative traits to discern pattern of phenotypic diversity and identifying accessions for economic traits and development of mini-core collection. The principal coordinate analysis revealed that out of the five qualitative traits, overall plant aspect contributed minimum to the percent variation in finger millet. Similarly, the principal component analysis revealed that of the 15 quantitative traits, seven (plant height, basal tillers, flag leaf blade length, flag leaf sheath length, length of inflorescence and longest finger and the panicle branches) contributed minimum to the variation. These eight traits could be considered of lesser importance in future research. The two traits, namely, days to flowering and inflorescence width accounted maximum for the differences between races and need to be given greater importance. Further, 10-key accessions were found (IEs 2457, 2820, 2921, 3025, 4443, 5129, 5182, 5239, 6337 and 6443) as source of diversity and suggested for use in hybridization program. The diversity pattern arrived from this study is from a core subset which is highly representative of entire collection. Therefore, results drawn could be considered as from entire finger millet collection (5940 accessions) held at the ICRISAT genebank and in the development of mini-core collection.

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*Milestone C.1.1.4: Core subset of foxtail millet established (CLLG/HDU, 2010)*

The entire foxtail millet collection has been stratified according to geographical regions and taxonomic races and data analysis for development of foxtail core subset is in progress.

CLL Gowda and HD Upadhyaya

***Output target C.2: Composite sets of germplasm established for utilization (2008)***

**Activity C.2.1: Establish germplasm composite sets of staple crops and small millets**

*Milestone C.2.1.1: Germplasm composite sets for groundnut, pigeonpea, and pearl millet (1000 accessions each) established (HDU/RB/CLLG/RKV/DH/CTH/SS/SC/KBS/RPT/KNR, 2007)*

**Composite collections developed and phenotypic diversity studied**

**Groundnut:** A composite collection of groundnut consisting of 1000 accessions was developed in collaboration with Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Brazil. The composite collection includes accessions from ICRISAT groundnut mini core collection (184), mini core comparator (184), Asia mini core

(50), high yield combined with large seed size and high shelling percentage from Asia core (60), released cultivars (36), biotic stresses resistant (104), abiotic stresses resistant (40), fresh seed dormancy (6), early maturity (25), large seed size (16), high shelling percentage (10), high oil content (9), high protein content (9), interspecific derivatives (5), earlier genotyped (18), and 52 accessions of 14 wild *Arachis* species. The composite includes accessions from EMBARPA for diverse origin and botanical varieties (130) and wild relatives (62) (Table 2). The composite collection includes 181 advanced lines, 245 breeding lines, 460 landraces, and 114 accessions of *Arachis* wild relatives. Region wise, Asia contributed maximum (44.5%) to the composite collections, followed by The Americas (31.2%), and Africa (18.4%). Europe and Oceania contributed less than 1% to the composite collection. The composite collection was phenotyped for 15 morphological and 16 agronomic characteristics in the rainy and postrainy seasons at ICRISAT Patancheru. The composite collection was also phenotyped for the traits related to drought like SPAD Chlorophyll Meter Reading (SCMR) and Specific Leaf Area (SLA) at 60 and 80 days after sowing in the rainy season. Large range of variation was observed for traits related to pod yield and drought (Table 3).

**Table 2. Composite collection of groundnut.**

| Character                                      | Accessions number | Character                                                         | Accessions number |
|------------------------------------------------|-------------------|-------------------------------------------------------------------|-------------------|
| <b>ICRISAT</b>                                 |                   |                                                                   |                   |
| Mini core                                      | 184               | Early maturing                                                    | 25                |
| Mini core comparator                           | 184               | Large seeded                                                      | 16                |
| Asia mini core                                 | 50                | High Shelling percentage                                          | 10                |
| Best accessions from Asia core                 | 60                | High oil content                                                  | 9                 |
| Released/elite cultivar/morphological variants | 36                | High protein content                                              | 9                 |
| <b>Trait specific</b>                          |                   | Interspecific derivatives                                         | 5                 |
| Resistant to biotic stresses                   | 104               | Accessions earlier genotyped (Morag Ferguson)                     | 18                |
| Resistant to abiotic stresses                  | 40                | Accessions of 14 wild <i>Arachis</i> species                      | 52                |
| Fresh seed dormancy                            | 6                 |                                                                   |                   |
| <b>EMBRAPA</b>                                 |                   |                                                                   |                   |
| Accessions of Wild <i>Arachis</i> species      | 62                | Cultivated accessions from diverse origin and botanical varieties | 130               |

**Table 3. Range and means in groundnut composite collection at ICRISAT Patancheru.**

| Characters                        | Minimum |           | Maximum |           | Mean    |           |
|-----------------------------------|---------|-----------|---------|-----------|---------|-----------|
|                                   | Rainy   | Postrainy | Rainy   | Postrainy | Rainy   | Postrainy |
| Days to 50% emergence             | 7       | 8         | 9       | 13        | 8       | 10        |
| Days to 50% flowering             | 19      | 27        | 34      | 48        | 25      | 33        |
| Plant height (cm)                 | 9       | 4         | 52      | 45        | 28.49   | 23.97     |
| Primary branches (no.)            | 2       | 3         | 9       | 9         | 5.02    | 5.16      |
| Leaflet length (mm)               | 32      | 29        | 87      | 93        | 56.28   | 54.56     |
| Leaflet width (mm)                | 13      | 12        | 41      | 45        | 25.31   | 25.41     |
| Days to maturity                  | 100     | 103       | 130     | 133       | 106     | 123       |
| Pods plant <sup>-1</sup> (no.)    | 2.2     | 5.5       | 64      | 41.8      | 19.82   | 18.62     |
| Pod length (mm)                   | 14.7    | 17        | 52.5    | 65.5      | 28.19   | 30.87     |
| Pod width (mm)                    | 8.2     | 9         | 18      | 132       | 12.37   | 13.43     |
| Seed length (mm)                  | 8.5     | 8.5       | 318.4   | 133       | 13.69   | 14.66     |
| Seed width (mm)                   | 5.5     | 6         | 11.4    | 14        | 7.95    | 8.82      |
| Pod yield plant <sup>-1</sup> (g) | 2.6     | 3.4       | 33.08   | 50.8      | 19.69   | 21.51     |
| Pod yield (kg ha <sup>-1</sup> )  | 441.7   | 491.7     | 4068.3  | 5275.0    | 2782.34 | 2867.45   |
| Shelling percentage               | 35      | 43.7      | 78      | 79        | 66.71   | 70.03     |
| 100-seed weight (g)               | 18      | 18        | 97      | 113       | 49.43   | 60.25     |

| Characters                                                   | Minimum |           | Maximum |           | Mean   |           |
|--------------------------------------------------------------|---------|-----------|---------|-----------|--------|-----------|
|                                                              | Rainy   | Postrainy | Rainy   | Postrainy | Rainy  | Postrainy |
| SPAD chlorophyll meter reading at 60 days after sowing (DAS) | 27.4    | -         | 61.38   |           | 44.08  | -         |
| Specific leaf area (60 DAS)                                  | 112.736 | -         | 268.07  |           | 187.40 | -         |
| SPAD chlorophyll meter reading (80 DAS)                      | 22.44   | -         | 56.32   |           | 42.48  | -         |
| Specific leaf area (80 DAS)                                  | 94.7224 | -         | 263.437 |           | 177.12 | -         |

- = not recorded

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**Pigeonpea:** A composite collection consisting of 1000 accessions was constituted based on phenotypic, taxonomic and characterization/evaluation data. The composite collection included accessions from the mini-core collection (146), mini-core comparator (146), core collection (236), superior morpho-agronomic traits (301), resistant to biotic stresses (74), resistant to abiotic stresses (14), elite/released cultivars (20) and 63 accessions of 7 wild species (Table 4). The pigeonpea composite set was evaluated in an augmented design using four control cultivars (UPAS 120, ICPL 87, Maruti and Gwalior 3) during rainy season at ICRISAT farm, Patancheru. Observations were recorded on 3 representative plants for 16 quantitative and 16 qualitative traits. Analysis of morpho-agronomic data revealed wide range of diversity for important traits (Table 5).

**Table 4. Composite collection of pigeonpea.**

| Type of material      | No. of accessions | Type of material                 | No. of accessions |
|-----------------------|-------------------|----------------------------------|-------------------|
| Mini core collection  | 146               | Abiotic stresses                 | 14                |
| Comparator            | 146               | Drought                          | 7                 |
| Checks                | 4                 | Water logging                    | 3                 |
| Resistant sources:    |                   | Salinity                         | 4                 |
| Biotic stresses       | 75                | <i>Trait specific selections</i> | 306               |
| Pod borer             | 20                | High nodulation                  | 2                 |
| Pod fly               | 5                 | Photoperiod insensitive          | 4                 |
| Pod borer and pod fly | 4                 | Agroforestry                     | 7                 |
| Wilt                  | 6                 | Forage                           | 6                 |
| Sterility mosaic      | 16                | Vegetable                        | 7                 |
| Alternaria blight     | 7                 | High protein                     | 20                |
| Phytophthora blight   | 6                 | Released cultivars               | 16                |
| Stem canker           | 5                 | Morpho-agronomic traits          | 244               |
| Nematodes             | 6                 | Wild species                     | 65                |
|                       |                   | Others                           | 244               |

**Table 5. Mean and range of diversity in pigeonpea composite collection.**

| Trait                              | Minimum | Maximum | Mean  |
|------------------------------------|---------|---------|-------|
| Leaf area (cm <sup>2</sup> )       | 3.4     | 98.1    | 22.3  |
| Days to 50% flowering              | 84.9    | 162.4   | 129.2 |
| Plant height (cm)                  | 81.2    | 207.0   | 152.7 |
| Primary branches per plant (no.)   | 6.5     | 24.0    | 12.8  |
| Secondary branches per plant (no.) | 3.0     | 35.1    | 8.7   |
| Tertiary branches per plant (no.)  | 0.8     | 5.0     | 2.0   |
| Days to 75% maturity               | 161.8   | 207.1   | 187.5 |
| No of racemes per plant            | 16.0    | 195.8   | 70.1  |
| Pod bearing length (cm)            | 40.1    | 84.0    | 62.3  |
| No of pods per plant               | 26.2    | 392.7   | 143.2 |
| Pod length (cm)                    | 3.0     | 8.8     | 5.1   |
| Seeds per pod (no.)                | 3.3     | 4.6     | 3.8   |
| 100-seed weight (g)                | 3.9     | 20.7    | 9.0   |

| Trait                    | Minimum | Maximum | Mean |
|--------------------------|---------|---------|------|
| Seed yield per plant (g) | 35.0    | 176.2   | 87.1 |
| Harvest index (%)        | 24.3    | 26.5    | 25.1 |
| Shelling percentage (%)  | 53.2    | 60.7    | 57.7 |

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RK Varshney, DA Hoisington and KB Saxena

**Pearl millet:** The pearl millet composite collection of 1000 accessions, includes core collection (504 accessions), biotic resistant sources (108 accessions), abiotic resistant sources (29 accessions), trait specific selections (247 accessions), released cultivars (5 accessions) breeding lines (47) and wild relatives (60 accessions). (Table 6). Composite collection was grown for characterization and regeneration during the rainy season in an augmented design using three control cultivars IP 17862 (ICTP 8203), IP 22281 and IP 3616, at ICRISAT, Patancheru. Observations were recorded on five representative plants in each accession for 18 morphoagronomic traits. Analysis of data revealed wide range of variation in the composite collection (Table 7).

**Table 6. Composition of pearl millet composite collection.**

| Type of material                         | No. of accessions |
|------------------------------------------|-------------------|
| Core collection                          | 504               |
| Tolerant to abiotic stresses             |                   |
| Drought                                  | 6                 |
| Heat                                     | 3                 |
| Salinity                                 | 20                |
| Resistant to biotic stresses             |                   |
| Downy mildew                             | 42                |
| Ergot                                    | 20                |
| Rust                                     | 23                |
| Smut                                     | 15                |
| Multiple disease resistant               | 8                 |
| High seed iron and zinc content (>42ppm) | 4                 |
| High seed protein (>17%)                 | 20                |
| Yellow endosperm                         | 2                 |
| Trait-specific selections                | 197               |
| Sweet stalks                             | 12                |
| Forage type                              | 8                 |
| Released cultivars                       | 5                 |
| Gene pools                               | 4                 |
| Wild relatives                           |                   |
| <i>P. mollissimum</i>                    | 6                 |
| <i>P. orientale</i>                      | 1                 |
| <i>P. pedicellatum</i>                   | 15                |
| <i>P. polystachion</i>                   | 15                |
| <i>P. ramosum</i>                        | 2                 |
| <i>P. schweinfurthii</i>                 | 1                 |
| <i>P. violaceum</i>                      | 20                |
| Contribution from crop improvement       | 47                |
| <b>Total</b>                             | <b>1000</b>       |



**Table 7. Range of variation in pearl millet composite collection evaluated in the rainy season.**

| Trait                                     | Minimum | Maximum | Mean   |
|-------------------------------------------|---------|---------|--------|
| Days to 50% flowering                     | 36      | 139     | 53.17  |
| Plant height (cm)                         | 22      | 241     | 158.68 |
| Total tillers (no.)                       | 1.0     | 8.0     | 1.56   |
| Productive tillers (no.)                  | 0.0     | 4.6     | 1.41   |
| Nodal tillers (no.)                       | 0.0     | 7.0     | 0.13   |
| Panicle exertion (cm)                     | -18.4   | 13.0    | 2.30   |
| Panicle length (cm)                       | 4.4     | 65.2    | 22.05  |
| Panicle width (mm)                        | 7.6     | 36.4    | 19.75  |
| 1000-seed weight (g)                      | 2.0     | 18.0    | 7.59   |
| Synchrony of panicle maturity (1-9 scale) | 2       | 8       | 4.94   |
| Panicle density (1-9 scale)               | 2       | 7       | 4.40   |
| Bristle length (1-9 scale)                | 1       | 6       | 1.49   |
| Fodder yield potential (1-9 scale)        | 2       | 8       | 4.50   |
| Seed yield potential (1-9 scale)          | 2       | 8       | 4.23   |
| Overall plant aspect (1-9 scale)          | 2       | 7       | 4.59   |

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***Output target C.3: Germplasm composite sets genotyped, diversity analysed, population structure assessed and reference sets of staple crops and small millets established (2010)***

**Activity C.3.1: Genotype composite collections for studying diversity and population structure and developing reference sets of staple crops and small millets**

*Milestone C.3.1.1: Chickpea composite set (3000 accessions) genotyped with SSR markers in collaboration with ICARDA (ICRISAT-HDU/SLD/DH/RKV/CLLG/SC; ICARDA- SMU, MB, BJT, 2006)*

Completed and reported in 2006.

*Milestone C.3.1.2: Sorghum composite set (3000 accessions) genotyped with SSR markers in collaboration with CIRAD and CAAS (ICRISAT- CTH/SS/HDU/PR/DH; CIRAD-CB; CAAS-, 2006)*

Completed and reported in 2006

*Milestone C.3.1.3: Reference collection of chickpea (300 accessions) established (HDU/ DH/RKV/CLLG/PMG, 2006)*

Completed and reported in 2006

*Milestone C.3.1.4: Four hundred wild and cultivated sorghums from 60 villages in Mali genotyped for 15 SSR. Write up report (FS + NARS, 2006)*

No report for 2007

*Milestone C.3.1.5: Diversity of wild and cultivated Pearl Millet in Niger published (FS, JN, BG, IRD, CIRAD, NARS, 2006)*

No report for 2007

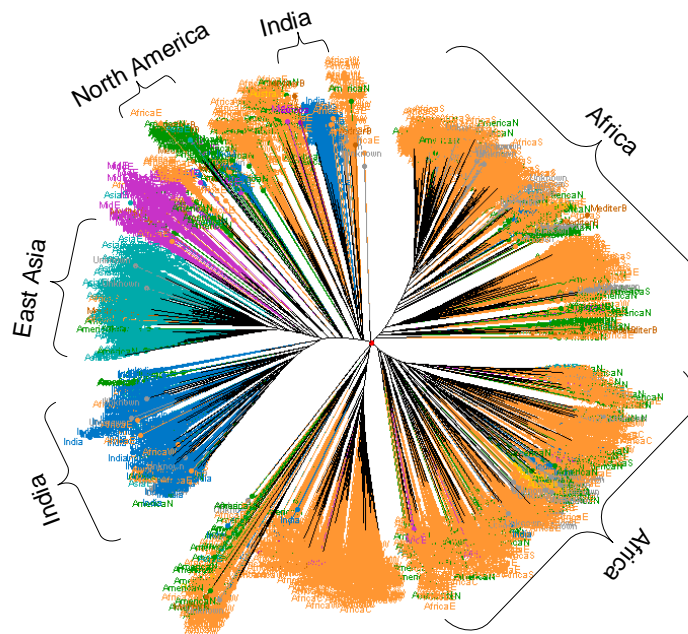
*Milestone C.3.1.6: Diversity and population structure of sorghum composite collection analyzed and reference set (300 accessions) established (CTH/HDU/SS/RKV/DH/CLLG/SC/JB/CB, 2007)*

**Diversity and population structure of sorghum composite collection**

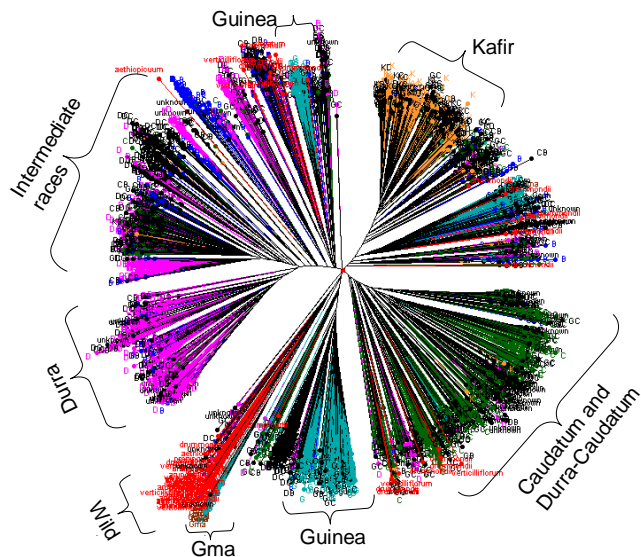
The GCP Global Composite Germplasm Collection of 3372 wild and cultivated sorghums includes 280 elite breeding lines and improved cultivars, 64 wild accessions, and >3000 landrace accessions selected from

previously defined core collections, for resistance/tolerance to production constraints, and/or for variation in other traits. A set of 48 sorghum SSR markers distributed across all ten linkage groups was chosen following preliminary analysis of 48 diverse genotypes with 104 available SSRs complemented by additional SSRs from CIRAD and ICRISAT. Diversity analysis was performed on 3367 accessions genotyped with 41 SSRs by CIRAD and ICRISAT. Breeding lines and wild accessions clustered separately from landraces, which exhibited structure explainable by geographic origin (Figure 1). Landrace population and wild accession substructure was further characterized within racial groups [five basic races and ten hybrid races]. Race *bicolor* showed little evidence of population structure, congruent with it being the original domesticate. Race *kafir* (largely from Southern Africa) was distinct (Figure 2). Accessions of the *durra*, *caudatum* and *guinea* races each formed several distinct geographic subgroups. The *guinea* race *margaritifera* group formed its own cluster, with the major cluster of wild accessions, suggesting independent domestication. Intermediate races behaved similarly. With all these 41 SSRs, 789 alleles were produced in sorghum global germplasm collection with an average of 19.24 alleles per markers with average polymorphic information content (PIC) of 0.6375. Sb5-206 markers produced higher PIC value (0.9382) with higher number of alleles (34). The average gene diversity among the global composite collection is 0.6743. Accessions from Africa continent contributed 87.3 % (689 alleles) of genetic diversity where as Asia contributed 612 alleles (77.5 %) to the global composite collection.

A sorghum SSR kit was developed and information regarding SSR kit is available at [http://sat.cirad.fr/sat/sorghum\\_SSR\\_kit/](http://sat.cirad.fr/sat/sorghum_SSR_kit/) and contains SSR primer sequence information, experimental protocol as well as details on expected allele sizes (based on sequencing) of PCR products for 10 diverse control accessions used to produce 3 control pools. These controlled genotypes will acts as a reference kit for any diversity analysis in sorghum.



**Figure1. Radial view of cluster analysis of global germplasm collection of sorghum using 41 SSR markers, based on geographic origin.**



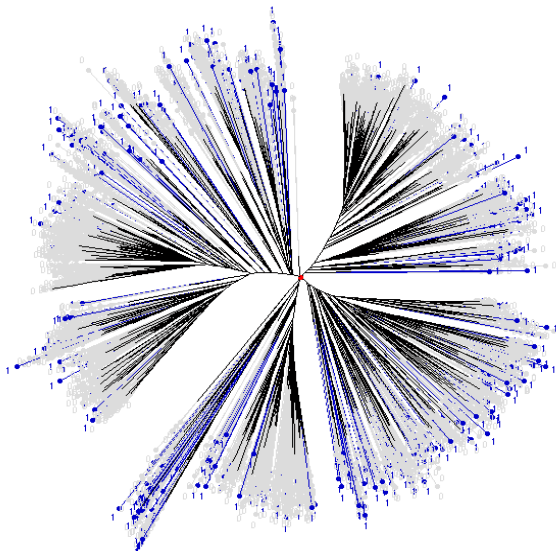
**Figure2. Radial view of cluster analysis of global germplasm collection of sorghum using 41 SSR markers, based on their race.**

**Sorghum reference set**

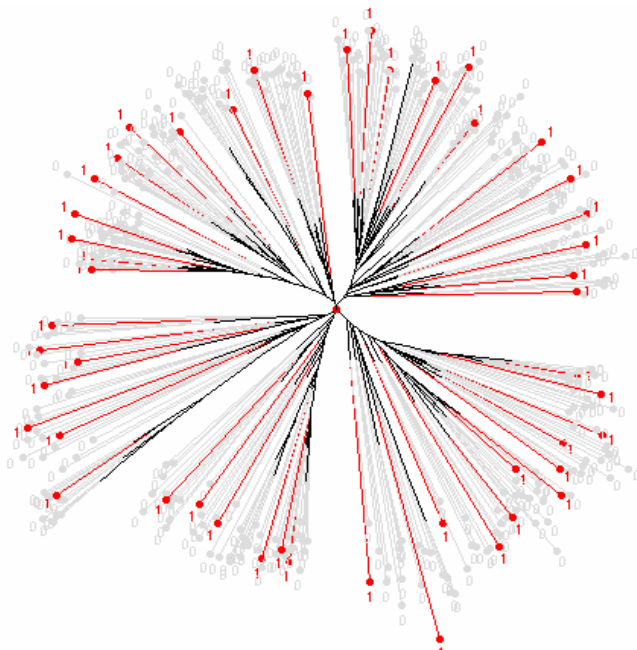
A reference set of 384 accessions (Figure 3) was then defined for allele mining which capturing 78% of alleles (615 alleles) produced in composite germplasm collection. This set consisting of 23 wild, 4 advanced cultivars, 25 breeding materials and 332 landraces. The average gene diversity among the reference set is 0.713 with an average PIC value 0.679, which is equal to global composite collection (Table 8). Reference set is being used for allele mining under ADOC project. From this set, we have identified a representative sample of 48 accessions (Figure 4) for use in marker genotype validation and as a smaller set with which to begin exploration of global sorghum germplasm.

**Table 8. Alleles, PIC value and gene diversity in the composite collection and reference set of sorghum.**

|                        | <b>Composite collection</b> | <b>Reference set</b> |
|------------------------|-----------------------------|----------------------|
| No. of Accessions      | 3367                        | 384                  |
| No. of Alleles         | 789                         | 615                  |
| Average PIC value      | 0.638                       | 0.679                |
| Average Gene Diversity | 0.674                       | 0.713                |



**Figure3. Distribution of reference set representing sorghum global composite germplasm diversity.**



**Figure 4. Distribution of 48 genotypes selected for validation project from reference subset of sorghum**

CT Hash, C Billot, P. Ramu, Jean-Francois Rami, L Gardes, RT Folkertsma, S Senthilvel, R Rivallan, HD Upadhyaya, M Deu, Y Li, T Wang and PLu

*Milestone C.3.1.7: Genetic diversity and population structure of chickpea assessed using composite collection (HDU/RKV/CLLG/DH/PMG/MB/SMU/JP/SC, 2007)*

***Genetic diversity in the chickpea composite collection:***

Chickpea composite collection consisting of 3000 accessions was genotyped with 50 SSR markers. Prior to analysis, the marker quality was checked using Allelobin software. Except for the marker TA28 (quality index as determined by its standard deviation,  $S_w = 0.536$ ), all other markers detected allele size expected on the basis of SSR repeat motif. Further, marker TR2 was dropped from the analysis as it showed very high level of heterozygosity (79.5%) while % heterozygosity for the other markers was  $\leq 3.2\%$  (likely due to a duplicate locus nature of TR2). A complete data set of 49 SSR loci on 2915 accessions of the composite collection was used for statistical analysis using PowerMarker V3.0 (<http://www.powermarker.net>) for estimating basic statistics [PIC, allelic richness as determined by a total number of the detected alleles and a number of alleles per locus, gene diversity ( $H_e$ ), occurrence of unique allele, rare and common alleles, and heterozygosity (%)] and DARwin-5.0 program for depicting the genetic structure of the composite collection and reference set.

The composite collection showed rich allelic diversity (1741 alleles, 35 alleles per locus, 968 rare and 773 common alleles). The gene diversity varied from 0.534 to 0.975, and the % heterozygosity ranged between 0.00 to 3.23% (Table 9). Average heterozygosity was maximum (11.51%) in wild types and ranged between 2.10% and 2.68% in desi, kabuli and pea types. Most of the markers, except CaSTMS21, NCPGR4, NCPGR6, NCPGR7, NCPGR19, TA142, TA3, and TS84, showed high PIC values (0.8135 to 0.9740), thus highly polymorphic.

The group-specific unique alleles were 114 in Kabuli, 306 in desi, 71 in wild *Cicer*; 117 in Mediterranean, 120 in West Asia (WA), and 119 in South and Southeast Asia (SSEA) (Table 10). Kabuli types as a group were more genetically diverse than other types. Only five alleles in pea-shaped chickpea differentiated it from other seed types. SSEA and WA shared 76, Mediterranean and SSEA 33, and Mediterranean and WA regions 39 common alleles. Desi and kabuli types shared 450 alleles.

A reference set consisting of 300 genetically diverse accessions was formed (based on simple matching distance matrix), capturing 1360 (78%) of the 1741 alleles detected in the composite collection, and possessing high gene diversity (0.540 to 0.999). A tree diagram (Figure 5) of the composite collection revealed two distinct clusters each in kabuli and desi types; however, a number of desi chickpeas also grouped into kabuli cluster and vice versa. The pea-shaped types were dispersed in both the groups. Most wild *Cicer* accessions formed one group within the cluster showing majority of the kabuli chickpea accessions. A tree diagram of this reference set (Figure 6) represented diversity from all directions of the original tree diagram of the composite collection (Figure 5).

**Table 9. Allelic composition, polymorphic information content (PIC), gene diversity, and heterozygosity (%) of the 49 SSR loci in global composite collection of chickpea.**

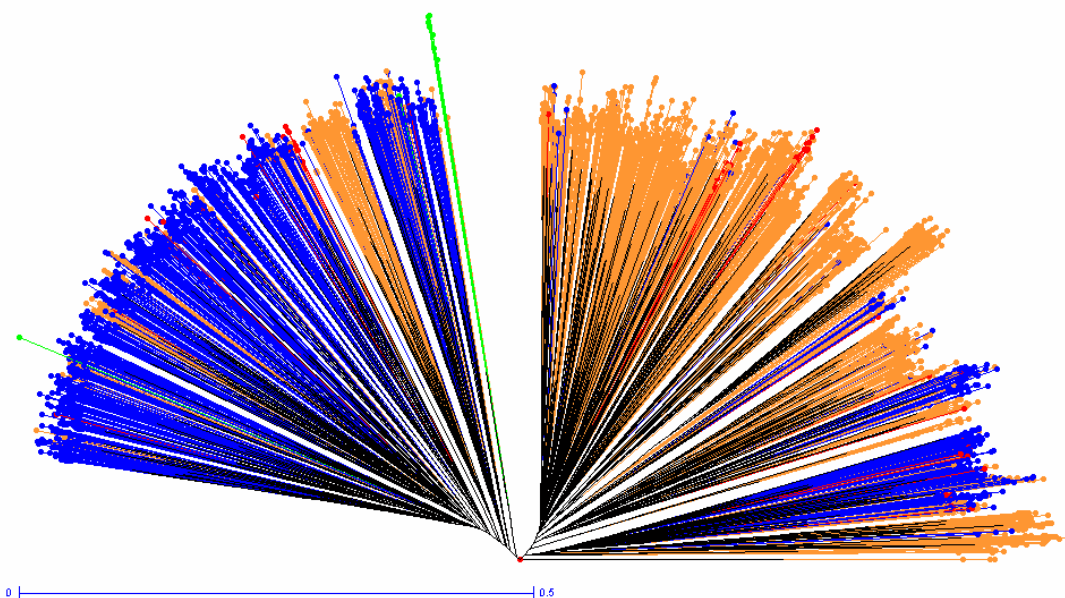
| Marker   | Allelic composition |                 |                  |                    |              | PIC  | Gene diversity | Heterozygosity (%) |      |
|----------|---------------------|-----------------|------------------|--------------------|--------------|------|----------------|--------------------|------|
|          | Allelic richness    | Size range (bp) | Rare allele (1%) | Common allele (1%) | Major allele |      |                |                    |      |
| CaSTMS2  | 29                  | 212-326         | 10               | 19                 | 245          | 10.3 | 0.929          | 0.933              | 2.43 |
| CaSTMS15 | 29                  | 209-368         | 13               | 16                 | 248          | 15.5 | 0.904          | 0.911              | 1.85 |
| CaSTMS21 | 20                  | 150-210         | 16               | 4                  | 168          | 61.7 | 0.468          | 0.534              | 0.17 |
| NCPGR4   | 14                  | 149-201         | 10               | 4                  | 193          | 52.6 | 0.606          | 0.650              | 0.21 |
| NCPGR6   | 21                  | 213-361         | 18               | 3                  | 255          | 48.9 | 0.559          | 0.628              | 0.11 |
| NCPGR7   | 15                  | 201-243         | 11               | 4                  | 223          | 49.8 | 0.549          | 0.619              | 0.11 |
| NCPGR12  | 27                  | 214-272         | 15               | 12                 | 254          | 28.8 | 0.813          | 0.832              | 0.14 |
| NCPGR19  | 26                  | 288-464         | 20               | 6                  | 300          | 45.8 | 0.591          | 0.652              | 0.11 |
| TA2      | 67                  | 93-251          | 47               | 20                 | 135          | 7.8  | 0.948          | 0.950              | 0.00 |
| TA3      | 29                  | 205-305         | 21               | 8                  | 293          | 30.6 | 0.727          | 0.764              | 0.00 |
| TA5      | 43                  | 155-293         | 30               | 13                 | 200          | 14.4 | 0.909          | 0.915              | 0.00 |
| TA8      | 33                  | 174-280         | 14               | 19                 | 204          | 12.7 | 0.913          | 0.919              | 0.00 |
| TA11     | 29                  | 158-296         | 17               | 12                 | 236          | 19.0 | 0.871          | 0.882              | 0.00 |
| TA14     | 41                  | 210-354         | 23               | 18                 | 267          | 14.2 | 0.904          | 0.911              | 0.80 |
| TA21     | 42                  | 275-422         | 21               | 21                 | 350          | 9.3  | 0.938          | 0.941              | 0.62 |
| TA22     | 50                  | 131-344         | 17               | 33                 | 203          | 7.7  | 0.962          | 0.964              | 0.40 |
| TA27     | 32                  | 192-306         | 19               | 13                 | 240          | 16.5 | 0.891          | 0.899              | 0.75 |
| TA28     | 58                  | 231-438         | 33               | 25                 | 336          | 8.5  | 0.958          | 0.960              | 0.25 |
| TA42     | 46                  | 101-251         | 27               | 19                 | 179          | 10.7 | 0.936          | 0.940              | 0.00 |
| TA46     | 24                  | 126-195         | 11               | 13                 | 153          | 21.7 | 0.843          | 0.858              | 0.34 |
| TA64     | 36                  | 173-284         | 15               | 21                 | 239          | 9.8  | 0.943          | 0.945              | 3.23 |
| TA71     | 41                  | 139-277         | 25               | 16                 | 202          | 13.9 | 0.917          | 0.922              | 0.85 |
| TA72     | 45                  | 177-375         | 33               | 12                 | 243          | 18.6 | 0.875          | 0.885              | 0.46 |
| TA76s    | 34                  | 149-314         | 24               | 10                 | 212          | 24.3 | 0.813          | 0.834              | 2.37 |
| TA78     | 39                  | 95-262          | 21               | 18                 | 199          | 14.9 | 0.905          | 0.911              | 0.00 |
| TA80     | 35                  | 148-275         | 16               | 19                 | 199          | 12.4 | 0.927          | 0.931              | 0.00 |
| TA96     | 48                  | 161-324         | 29               | 19                 | 275          | 14.0 | 0.918          | 0.923              | 0.00 |
| TA113    | 19                  | 151-238         | 8                | 11                 | 202          | 27.6 | 0.851          | 0.863              | 1.63 |
| TA116    | 33                  | 159-276         | 22               | 11                 | 180          | 22.3 | 0.838          | 0.853              | 0.89 |
| TA117    | 36                  | 173-323         | 18               | 18                 | 248          | 9.8  | 0.929          | 0.933              | 0.62 |
| TA118    | 43                  | 116-263         | 18               | 25                 | 182          | 9.9  | 0.949          | 0.952              | 1.55 |
| TA130    | 23                  | 185-254         | 10               | 13                 | 221          | 34.0 | 0.822          | 0.835              | 1.19 |
| TA135    | 21                  | 125-221         | 8                | 13                 | 194          | 24.6 | 0.850          | 0.864              | 2.70 |
| TA142    | 23                  | 113-197         | 14               | 9                  | 128          | 36.2 | 0.758          | 0.785              | 0.57 |
| TA144    | 56                  | 179-287         | 37               | 19                 | 239          | 16.2 | 0.931          | 0.935              | 0.00 |
| TA176    | 64                  | 146-365         | 25               | 39                 | 221          | 5.6  | 0.974          | 0.975              | 0.00 |
| TA194    | 29                  | 87-291          | 17               | 12                 | 96           | 26.3 | 0.867          | 0.877              | 0.00 |
| TA200    | 39                  | 250-379         | 23               | 16                 | 286          | 15.9 | 0.917          | 0.922              | 1.71 |
| TA203    | 56                  | 160-294         | 27               | 29                 | 214          | 5.8  | 0.964          | 0.965              | 0.00 |
| TA206    | 32                  | 350-449         | 18               | 14                 | 386          | 16.1 | 0.898          | 0.906              | 0.71 |
| TAA58    | 45                  | 205-349         | 21               | 24                 | 274          | 7.2  | 0.956          | 0.957              | 1.33 |
| TAASH    | 39                  | 364-496         | 20               | 19                 | 436          | 10.6 | 0.930          | 0.934              | 0.70 |

| Marker | Allelic composition |                 |                  |                    |              |      | PIC   | Gene diversity | Heterozygosity (%) |
|--------|---------------------|-----------------|------------------|--------------------|--------------|------|-------|----------------|--------------------|
|        | Allelic richness    | Size range (bp) | Rare allele (1%) | Common allele (1%) | Major allele |      |       |                |                    |
| TR1    | 62                  | 133-324         | 45               | 17                 | 200          | 11.4 | 0.929 | 0.934          | 0.00               |
| TR7    | 26                  | 167-248         | 8                | 18                 | 206          | 16.7 | 0.891 | 0.899          | 2.44               |
| TR29   | 32                  | 127-259         | 15               | 17                 | 217          | 15.0 | 0.916 | 0.921          | 2.08               |
| TR31   | 16                  | 165-324         | 7                | 9                  | 201          | 22.8 | 0.843 | 0.859          | 2.66               |
| TR43   | 53                  | 249-474         | 26               | 27                 | 300          | 7.0  | 0.956 | 0.958          | 2.45               |
| TS45   | 26                  | 134-274         | 17               | 9                  | 244          | 21.6 | 0.842 | 0.858          | 0.00               |
| TS84   | 15                  | 197-266         | 8                | 7                  | 227          | 44.4 | 0.596 | 0.656          | 0.32               |
| Total  | 1741                |                 | 968              | 773                |              |      |       |                |                    |
| Mean   | 35                  |                 |                  |                    |              |      |       |                |                    |

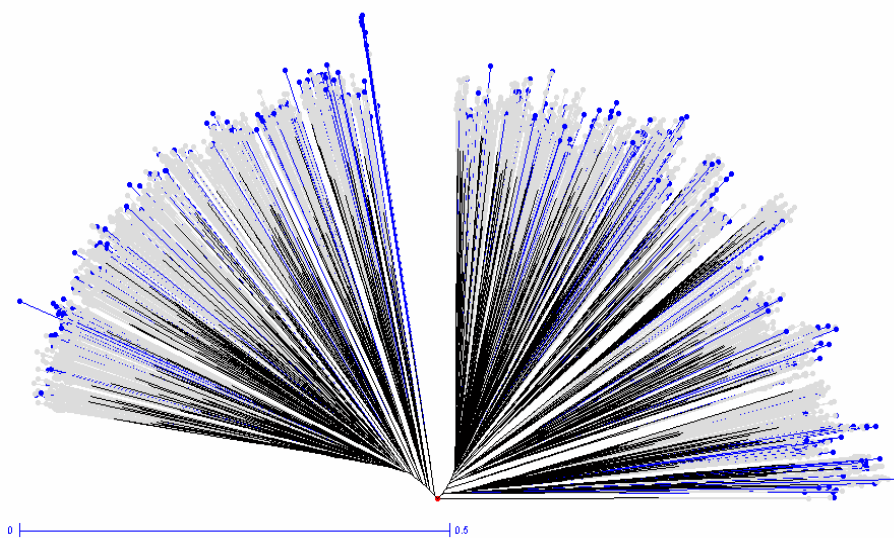
**Table 10. Molecular diversity of accessions related to their biological and geographical classification of the 2915 accessions included in chickpea composite collection.**

| Biological classification          | Number of accessions | Allelic composition    |                    |                  |               | Gene diversity      | Heterozygosity (%) |
|------------------------------------|----------------------|------------------------|--------------------|------------------|---------------|---------------------|--------------------|
|                                    |                      | Allelic richness       | Common allele (1%) | Rare allele (1%) | Unique allele |                     |                    |
| <b>Biological classification</b>   |                      |                        |                    |                  |               |                     |                    |
| Kabuli                             | 1167                 | 1333 (27) <sup>+</sup> | 716                | 617              | 114           | 0.849(0.254-0.964)  | 2.68               |
| Desi                               | 1668                 | 1525 (31)              | 726                | 799              | 306           | 0.850 (0.417-0.974) | 2.10               |
| Pea-shaped                         | 70                   | 691 (14)               | 684                | 7                | 5             | 0.842 (0.484-0.955) | 2.18               |
| <b>Wild <i>Cicer</i> species</b>   | 10                   | 349 (7)                | 349                | 0                | 71            | 0.794 (0.444-0.890) | 11.51              |
| <b>Geographical classification</b> |                      |                        |                    |                  |               |                     |                    |
| Africa                             | 150                  | 858 (18)               | 655                | 203              | 10            | 0.806 (0.301-0.949) | 1.90               |
| CIS                                | 44                   | 598 (12)               | 598                | 0                | 0             | 0.799 (0.376-0.799) | 2.83               |
| Europe                             | 65                   | 669 (14)               | 663                | 6                | 3             | 0.809 (0.175-0.936) | 2.37               |
| Mediterranean                      | 619                  | 1324 (26)              | 712                | 612              | 117           | 0.836 (0.260-0.965) | 2.97               |
| North and central America          | 94                   | 747 (15)               | 747                | 0                | 6             | 0.834 (0.467-0.948) | 1.89               |
| South America                      | 49                   | 541 (11)               | 541                | 0                | 3             | 0.777 (0.119-0.941) | 2.39               |
| South and southeast Asia           | 1138                 | 1367 (28)              | 671                | 696              | 119           | 0.826 (0.347-0.969) | 2.13               |
| Unknown region                     | 34                   | 602 (12)               | 602                | 0                | 15            | 0.853 (0.545-0.939) | 1.71               |
| West Asia                          | 720                  | 1369 (28)              | 811                | 558              | 120           | 0.869 (0.478-0.967) | 2.37               |

<sup>+</sup> Average number of alleles



**Figure 5. Radial diagram of composite collection (49 SSR loci data on 2915 accessions) showing desi (orange color), kabuli (blue color), pea shaped (red color) and wild types (green color) as revealed by DARwin-5.**



**Figure 6. 300 accessions representing reference set (blue color) and the remaining 2615 accessions of the composite collection (gray color)**

HD Upadhyaya, SL Dwivedi, SM Udupa, M Baum,  
R Varshney, DA Hoisington, CLL Gowda and BJ Furman

*Milestone C.3.1.8: Four-hundred wild and cultivated sorghum accessions from Kenya genotyped for 30 SSR markers (DK/SdV/FS/NARS, 2007)*



For genotyping, the 354 accessions of wild and cultivated sorghums that were collected under the BBI project were combined with another 100 acquired from the genebank of Kenya to cover collection gaps in parts of central Rift valley. Genotyping is in progress for 30 SSR markers and has been completed for at least 300 accessions and 27 SSR markers. Preliminary results indicate little genetic differentiation between cultivated and wild sorghum ( $F_{st} = 0.04$ ).

D Kiambi, S de Villiers, F Sagnard and NARS

*Milestone C.3.1.9: Paper accepted on the in situ diversity of 472 Sorghum varieties collected in 79 villages in Niger (FS/BG/JN/NARS/CIRAD/IRD, 2007)*

A paper entitled “Niger-wide assessment of in situ sorghum genetic diversity with microsatellite markers” was accepted for publication in the Theoretical and Applied Genetics (Authors: Deu M, Sagnard F, Chantreau J, Calatayud C, Hérault D, Mariac C, Pham JL, Vigouroux Y, Kapran I, Traore PS, Mamadou A, Gerard B, Ndjeunga J and Bezançon G). The paper reports on the genetic analysis of 484 sorghum varieties collected in 79 villages evenly distributed across Niger, using 28 microsatellite markers. Diversity varied between eastern and western Niger, and allelic richness was lower in the eastern part of the country. Genetic differentiation between botanical races was the first structuring factor ( $F_{st} = 0.19$ ), but the geographical distribution and the ethnic group to which farmers belonged were also significantly associated with genetic diversity partitioning. Gene pools are poorly differentiated among climatic zones. The geographical situation of Niger where typical western African (*guinea*), central African (*caudatum*), and eastern Sahelian African (*durra*) sorghum races converge explained the high observed genetic diversity and was responsible for the interactions among the ethnic, geographical and botanical structure revealed in our study. After correcting for the structure of botanical races, spatial correlation of genetic diversity was still detected within 100 km, which may hint at limited seed exchanges between farmers. Sorghum domestication history, in relation to the spatial organization of human societies, is therefore key information for sorghum *in situ* conservation programs in sub-Saharan Africa.

D Kiambi, S de Villiers, F Sagnard and NARS

*Milestone C.3.1.10: Comparative phylogeography of wild, weedy and cultivated sorghums in Mali published (FS/PST/NARS/CIRAD, 2008)*

All microsatellite datasets were assembled in 2007 after the last stay of Dékoro Dembélé at CIRAD Montpellier from March to June 2007. M.Sc. thesis of Mr Dembélé entitled “Comparative phylogeography of wild, weedy and cultivated Sorghums in Mali” was completed and officially presented on 14 November 2007 at the University of Bamako.

D Kiambi, S de Villiers, F Sagnard and NARS

*Milestone C.3.1.11: Comparative phylogeography of wild, weedy and cultivated sorghums in Kenya published (FS/SdV/DK/NARS/University of Free State, 2008)*

The collection of wild, weedy and cultivated sorghum in Kenya was completed. SSR genotyping for 27 SSR markers expected to be completed by December 2007.

D Kiambi, S de Villiers, F Sagnard and NARS

*Milestone C.3.1.12: Diversity assessment of sorghum and chickpea published (HDU/CTH/RKV/CLLG/SS/DH/SC/JB, 2009)*

Data analysis of chickpea composite collection is in progress.

HD Upadhyaya, SL Dwivedi,  
RK Varshney and CLL Gowda

*Milestone C.3.1.13: Data sets for sorghum and chickpea composite set made available globally via Internet (JB/HDU/CTH/RKV/CLLG/SS/DH/SC, 2008)*

ICRISAT produced 105,000 (3,000 x 35) data points and ICARDA produced 45,000 (3,000 x 15) data points of chickpea composite collection. Combined together 150,000 data points were generated. After quality assessment 145750 (2915 x 50) data points were validated for final contribution to the GCP repository with a total of 3.25% missing data points. The two datasets (ICRISAT and ICARDA) have been submitted to the GCP Central



Registry ([http://gcpcr.grinfo.net/index.php?app=datasets&inc=dataset\\_details&dataset\\_id=625](http://gcpcr.grinfo.net/index.php?app=datasets&inc=dataset_details&dataset_id=625)). These markers can be used for describing the structure in a germplasm collection.

HD Upadhyaya, B Jayashree, RK Varshney,  
CLL Gowda, DA Hoisington and S Chandra

*Milestone C.3.1.14: Diversity and population structure of groundnut composite collection analyzed and reference set (300 accessions) established (HDU/RB/RKV/CLLG/DH/SC/JB, 2008)*

#### **Genetic diversity in the groundnut composite collection**

A composite collection, consisting of 1000 accessions has been marker profiled, using 21 SSR markers and high throughput assay (ABI3700). ICRISAT produced 19131 (911 X 21 SSRs) datapoints, while data from EMBRAPA are still awaited. After quality assessment, 17892 (852 X 21) data points were validated for final contribution to the GCP repository with a total of 2.9% missing datapoints. Preliminary analysis detected a total of 490 alleles in the composite collection, of which 244 were rare and 246 common alleles. Gene diversity ranged from 0.559 to 0.926, with an average of 0.819. Group-specific unique alleles were 101 in wild *Arachis*, 50 in subsp. *fastigiata*, and only 11 in subsp. *hypogaea*. Accessions from Americas revealed highest number of unique alleles while Africa and Asia, respectively, had only six and nine unique alleles. The two subsp. *hypogaea* and *fastigiata* shared 70 alleles. The wild *Arachis*, in contrast, shared only 15 alleles with subsp. *hypogaea* and 32 alleles with subsp. *fastigiata*. A tree-diagram using DARwin-5.0 separated majority of the subsp. *hypogaea* from the subsp. *fastigiata* while wild *Arachis* accessions clustered with subsp. *hypogaea*. A reference set consisting of 300 most diverse accessions has been established, that captured 95% of the 490 alleles detected in the composite collection (852 accessions).

HD Upadhyaya, R Bhattacharjee, RK Varshney,  
CLL Gowda and DA Hoisington

*Milestone C.3.1.15: Diversity and population structure of pigeonpea composite collection analyzed and reference set (300 accessions) established (HDU/RB/RKV/DH/SC/JB, 2009)*

#### **Genetic diversity in the pigeonpea composite collection**

The pigeonpea composite collection, consisting of 1000 accessions was established at ICRISAT using the available phenotypic characterization and evaluation data. The collection comprised accessions of pigeonpea mini-core (146), comparator mini-core, and representative accessions of landraces, breeding lines, genetic stocks, wild species and four control cultivars. At ICRISAT, this composite collection was genotyped using 20 SSR markers. A fluorescent-based multiplex genotyping system was then used to generate six multiplexes and these were used to fingerprint the composite collection. The amplified PCR products were separated by capillary electrophoresis in an automated system using ABI 3700. SSR fragment sizes were called to two decimal places using the Genotyper v3.7 software. Final binning was carried out following Allelobin software for calling the alleles. Quality check for markers and data is in progress.

HD Upadhyaya, R Bhattacharjee, RK Varshney,  
CLL Gowda and DA Hoisington

*Milestone C.3.1.16: Datasets for groundnut and pigeonpea composite set made available globally via Internet (JB/HDU/RKV/DH/RB/CLLG/SC/KBS, 2010)*

#### **Groundnut composite collection**

ICRISAT produced 19131 (911 X 21 SSR) datapoints in groundnut composite collection and the same will be delivered to GCP repository soon. After quality control, 7892 data points (852 X 21 SSR) were used in structure and diversity analysis and would be contributed to the GCP registry.

HD Upadhyaya, B Jayashree, RK Varshney, DA Hoisington,  
R Bhattacharjee, CLL Gowda and KB Saxena

#### **Pigeonpea composite collection**

ICRISAT produced 20000 (1000 X 20 SSR) data points in groundnut composite collection and the same will be delivered to GCP repository soon. After quality control, 19040 data points (952 X 20 SSR) were used in structure and diversity analysis and would be contributed to the GCP registry.

HD Upadhyaya, B Jayashree, RK Varshney, DA Hoisington,  
R Bhattacharjee, CLL Gowda and S Chandra

*Milestone C.3.1.17: Diversity and population structure of finger millet and foxtail millet composite collections analyzed and reference sets (300 accessions finger millet, 200 foxtail millet) established (HDU/CTH/RKV/SS/DH/CLLG/SC/JB, 2009)*

### Genetic diversity in the finger millet composite collection

A complete data set of 20 SSRs on 1000 accessions was used to dissect the structure and diversity in composite collection and for the formation of reference set. The composite set was planted in the field and DNA was extracted from 20 days old seedlings. DNA concentration checked and normalized in to 5 ng/ml working solution for genotyping. Twenty polymorphic SSR markers were screened from a set of 31 markers on eight genotypes. The composite collection was genotyped with 4 checks repeating in every 96-well PCR plate with 20 markers by Automated gene analyzer (ABI 3700). The electrophoresis data were exported to Genescan and Genotyper software to retrieve allele calling. The called alleles were binned using Allelobin and the quality index of the marker calculated. Allelic data from the selected markers based on quality index are used for DARwin 5 for further statistical analysis (Tables 11 and 12). Data quality was monitored on 20,000 (1000 accessions X 20 SSR markers) and 19180 datapoints (959 accessions X 20 SSRs) with 4% missing values used for further analysis. A total of 231 (121 common and 110 rare) alleles were detected in the composite collection. Gene diversity varied from 0.20 to 0.85%. On average, 7.4 alleles were detected in Race *Compacta*, 6.5 in *Elongata*, 8 in *Plana*, 10 in *Vulgaris*, 4 in *Spontanea*, 2 in *Africana*, and origin wise 8 in south Africa, 3 west Africa, 9 in south Asia, 2 in Europe, 3 in America and 5 of unknown origin. Group specific unique alleles were observed 29 in East Africa, 12 in South Asia, 11 in Southern Africa, 1 in central Africa and 2 of unknown origin and race wise 37 in *Vulgaris*, 5 in *Plana*, 4 in *Africana* and 2 in *Compacta*. The average multiple alleles was maximum (13.57%) in wild spontaneae types and ranged 1.6 to 9% in other races. The gene diversity was maximum in wild *Spontanea* race. A reference set consisting 300 genetically diverse accessions (Figure 7) was identified (based on simple matching distance matrix), capturing 206 (89.2%) of the 231 alleles detected in the composite collection, and possessing high gene diversity (0.31 to 0.85%) and mean heterozygosity of 0.0918.

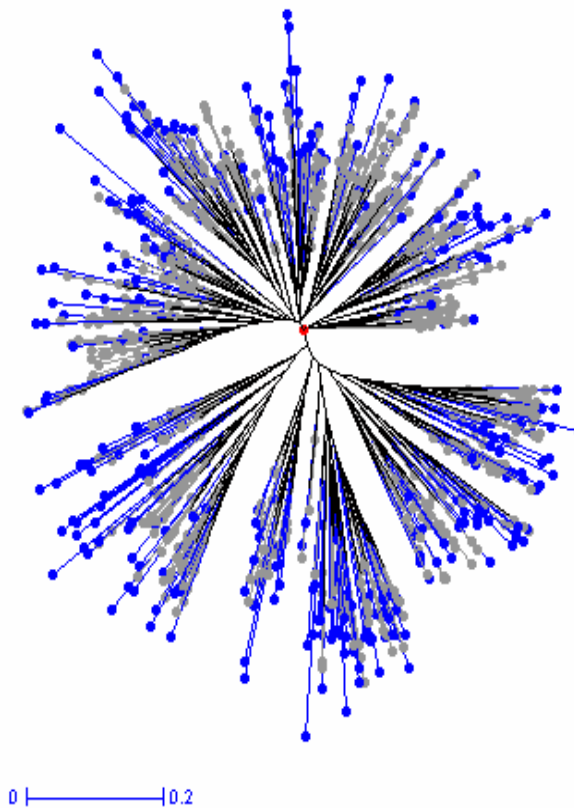
The common alleles shared by two groups were 15 for East Africa and South Asia, 5 for East Africa and Southern Africa, 3 for South Asia and southern Africa and race wise 26 in *Vulgaris* and *Plana* and 2 in *Vulgaris* and *Africana*.

**Table 11. Number of alleles, gene diversity, heterozygosity and PIC in the finger millet composite collection based on origin.**

| S. No | Origin          | Major allele frequency | Sample size | Allele (No) | Gene diversity | Multiple alleles (%) | PIC  |
|-------|-----------------|------------------------|-------------|-------------|----------------|----------------------|------|
| 1     | Central Africa  | 0.551                  | 8           | 3.7         | 0.569          | 0.129                | 0.52 |
| 2     | East Africa     | 0.578                  | 429         | 9.9         | 0.565          | 0.087                | 0.52 |
| 3     | Southern Africa | 0.619                  | 164         | 8.1         | 0.524          | 0.09                 | 0.48 |
| 4     | West Africa     | 0.682                  | 7           | 2.6         | 0.42           | 0.058                | 0.37 |
| 5     | South Asia      | 0.615                  | 316         | 8.8         | 0.537          | 0.084                | 0.5  |
| 6     | Europe          | 0.6                    | 4           | 2.2         | 0.435          | 0.046                | 0.36 |
| 7     | America         | 0.594                  | 4           | 2.6         | 0.497          | 0.117                | 0.43 |
| 8     | Unknown         | 0.6                    | 27          | 5.3         | 0.573          | 0.085                | 0.53 |

**Table 12. Number of alleles, gene diversity, heterozygosity and PIC in the finger millet composite collection based on races.**

| S. No | Origin     | Major Allele Frequency | Sample Size | Allele (No) | Gene diversity | Multiple alleles (%) | PIC  |
|-------|------------|------------------------|-------------|-------------|----------------|----------------------|------|
| 1     | Compacta   | 0.587                  | 127         | 7.4         | 0.553          | 0.095                | 0.51 |
| 2     | Elongata   | 0.602                  | 69          | 6.5         | 0.542          | 0.078                | 0.5  |
| 3     | Plana      | 0.581                  | 201         | 8           | 0.564          | 0.073                | 0.52 |
| 4     | Vulgaris   | 0.59                   | 551         | 10.3        | 0.553          | 0.09                 | 0.51 |
| 5     | Spontaneae | 0.516                  | 7           | 4           | 0.611          | 0.136                | 0.57 |
| 6     | Africana   | 0.633                  | 3           | 2.1         | 0.422          | 0.017                | 0.35 |



**Figure 7. Radial diagram of the reference collection (blue color) and the remaining accessions of the composite collection (grey color)**

A Bharathi, HD Upadhyaya, CLL Gowda,  
RK Varshney, CT Hash and DA Hoisington

**Genetic diversity in the foxtail millet composite collection**

The composite collection of foxtail millet (500 accessions) was planted in the field and DNA was extracted from 20 days old seedlings. DNA concentration checked and normalized to 5 ng/ml working solution for genotyping. There were no SSR markers available in the public domain. So initially 48 markers from pearl millet and 31 markers from finger millet are being screened across 8 diverse genotypes and 10 markers have been identified as polymorphic. Genotyping has started with 10 markers. In addition, four recently published EST SSR markers were used for genotyping. To provide the required number of markers, we screened some more unpublished 30 EST SSR markers from pearl millet and 10 showed good transferability to foxtail millet. Genotyping with remaining markers is in progress.

HD Upadhyaya, A Bharathi, CLL Gowda,  
RK Varshney, CT Hash and DA Hoisington

*Milestone C.3.1.18: Diversity and population structure of pearl millet composite collection analysed and reference set (300 accessions) established (H DU/CTH/ R KV/SS/DH/CLLG/SC/JB, 2010)*

No report for 2007

*Milestone C.3.1.19: Diversity assessment of pearl millet published (H DU/CTH/SS/RKV/DH/SC/JB, 2010)*

No report for 2007

*Milestone C.3.1.20: Data sets for pearl millet, finger millet, and foxtail millet composite sets made available globally via Internet (JB/HDU/CTH/SS/RKV/CLLG/DH/SC, 2010)*

No report for 2007

### **Activity C.3.2: Diversity assessment in groundnut rosette virus resistant germplasm**

*Milestone C.3.2.1: The diversity of the sources of resistance to the groundnut rosette virus in groundnut assessed and documented (ESM/HDU/Others, 2009)*

No report for 2007

### **Activity C.3.3: Phenotypic and genotypic diversity assessment of sorghum germplasm in eastern and southern Africa**

*Milestone C.3.3.1: Phenotypic characterization of sorghum germplasm held by ESA NARS completed (DK, 2007)*

In phenotyping, subsets of between 164 and 298 accessions per country have been used. These comprise landraces, farmer varieties, improved cultivars and breeding lines. Each subset was replicated in two different sites representing different agro-climatic zones and/or geographic origin of material. All the accessions were planted in both locations using different randomization. In each site, 3 replicates per accession were used in order to maintain scientific standards and satisfy statistical analysis requirements. The "Balanced Lattice" design of 14x14 with 196 genotypes was used and smaller designs were used when and where the samples were less than 196. The characterization was done for 27 morphological characters representing different growth stages, qualitative and quantitative traits. Three plants per accession were used for scoring and the means obtained (for quantitative characters). For qualitative characters, the numerical codes provided in the descriptor list were used instead of the actual characters. In case of intra-accession variation, codes of the different characters observed were recorded and the visual assessment of the dominant character noted as well. The three plants to be scored per row were selected randomly and tagged just before flowering to avoid any bias. A total of 1544 accessions have been phenotyped in at least one site. In Burundi, Rwanda, Eritrea, Sudan and Tanzania phenotyping has been finalized in two sites while in Kenya, Ethiopia and Uganda phenotyping has been completed in the first sites and it is now being done in the second sites. Seven countries have been supplied with computer hardware and software to enhance phenotyping data documentation and retrieval.

D Kiambi

*Milestone C.3.3.2: Molecular characterization of germplasm held by ESA NARS completed (DK, 2007)*

The PCR conditions for 40 SSR markers have been optimized and genotyping for molecular characterization has been done using these markers. The markers used and their repeat motifs, chromosome location, forward and reverse sequences, annealing temperatures, and allele sizes have been determined and documented. The number of total alleles, common and rare alleles with allelic frequencies of at least 5% and the polymorphism information content (PIC) values were determined for each SSR marker. Pair-wise genetic similarities between individual accessions were calculated using PowerMarker v.3.25. Multi-Dimensional Scatter plots were drawn to visualize the inter-relationship among the accessions. The Nei's genetic diversity among accessions was estimated using the program PowerMarker based on estimated allele frequencies, with the following statistics: average number of common alleles per locus (allelic frequencies of at least 5%), number of polymorphic loci, percentages of polymorphic loci, observed heterozygosity (Hobs) and average expected gene diversity corrected for small sample sizes (Hunb) (Nei, 1978). Allele frequency based pair-wise genetic distances between accessions were calculated using PowerMarker v3.25 based on Rogers distance matrix. The resulting distance matrix was subjected to sequential agglomerative hierarchical nested (SAHN) clustering using un-weighted pair-group method analysis (UPGMA). Distance matrices and dissimilarity indices were also generated using Dice's coefficient features in DARwin ver. 4.0 to generate dendograms showing the clustering of accessions. A total of 886 accessions from Tanzania, Kenya, Eritrea, Burundi and Rwanda have been genotyping using 40 SSR markers resulting in 3,55,440 data points. Data analysis for 200 accessions from Tanzania has been completed while the analysis for materials from the other countries is well underway in order to determine the diversity and genetic relations within and between the countries. A paper on molecular characterization of sorghum germplasm in east and central Africa (Authors: Kiambi DK, Ferguson M, Hoisington D, Salih S and

Kawuki R) was presented at the International Conference on Seeds, Breeding Systems and Biotechnology, held in Maputo, 25<sup>th</sup> to 29<sup>th</sup> April 2007.

D Kiambi

*Milestone C.3.3.3: Phenotypic and molecular data for sorghum standardized and analyzed (DK, 2008)*

No report for 2007

**Activity C.3.4: Development of a database for documentation and retrieval of morphological and molecular data**

*Milestone C.3.4.1: Database of passport information, farmer-knowledge, pedigrees, phenotyping and genotyping data of sorghum accessions held in ESA national genebanks and international nurseries developed (DK, 2008)*

No report for 2007

**Output target C.4: Core, mini-core, and or reference sets of germplasm evaluated for utilization in Asia (2009)**

**Activity C.4.1: Evaluate core/mini-core/reference sets of staple crops and small millets for agronomic traits**

*Milestone C.4.1.1: Mini-core collections of chickpea, groundnut, and pigeonpea evaluated in multilocations in Asia (HDU/CLLG/NARS, 2008)*

**Evaluation of mini-core collections of chickpea**

Evaluated 211 accessions of chickpea mini-core collection with three desi (Annigeri, G 130, and ICCV 10) and two kabuli (L 550 and KAK 2) control cultivars in an augmented design experiment at ICRISAT Patancheru. Among desi types, 22 accessions produced higher seed yield (3.07 to 4.20 t ha<sup>-1</sup>) than Annigeri (3.06 t ha<sup>-1</sup>), G 130 (2.47 t ha<sup>-1</sup>), and ICCV 10 (2.86 t ha<sup>-1</sup>). ICCs 13892, 2263, 15868, 1180, and 6802 (3.71 to 4.20 t ha<sup>-1</sup>) were the best five high yielding accessions among desi types. The best five accessions in desi type were ICCs 4841, 14595, 13816, 5337, and 7819 with greater seed weight (26.3 to 28.9 g) and greater seed yield (3.08 to 4.21 t ha<sup>-1</sup>) in comparison to all the three desi control cultivars Annigeri (22.1 g), G 130 (11.4 g), and ICCV 10 (17.5 g). Among kabuli types, 20 accessions (2.3 to 4.21 t ha<sup>-1</sup>) produced higher seed yield than L 550 (2.12 t ha<sup>-1</sup> seed yield and 20.5 g 100-seed weight) and KAK 2 (1.80 ha<sup>-1</sup> seed yield and 38.3 g 100-seed weight). ICCs 8155, 12328, and 14199 were the best large-seeded kabuli accessions (40.0 to 43.9 g 100-seed weight) combined with higher seed yield (2.46 to 3.50 t ha<sup>-1</sup>). Among the pea-shaped ICC 9862 (3.15 t ha<sup>-1</sup>) and ICC 9895 (3.45 t ha<sup>-1</sup>) produced greater seed yield than all the five control cultivars.

HD Upadhyaya and CLL Gowda

**Evaluation of mini-core collections of pigeonpea**

Evaluated 146 accessions of pigeonpea germplasm mini-core collection and four control cultivars of extra early (ICPL 87), early (UPAS 120), medium (Maruti) and late (Gwalior 3) maturing groups at Bangalore, Dholi, Dantiwada, Jalna, Kanpur and Khargone locations in India, during 2006 rainy season. Analysis of data from Khargone location indicated the superiority of several germplasm accessions over extra early (30 accessions) and medium maturing checks for seed yield per plant. Nineteen accessions over extra early control and 10 accessions over medium maturing control were found as superior for harvest index. Two accessions ICP 14900 and ICP 1156, which flowered in less than 100 days produced higher seed yield than the extra early control than cultivar ICPL 87. Only two accessions ICP 1156 and ICP 15068 flowered earlier (91 days) extra early control ICPL 87 (93 days). Data from other locations is awaited.

VS Kandalkar (Khargone), HD Upadhyaya and CLL Gowda

**Evaluation of mini-core collections of groundnut**

Evaluated 184 accessions of groundnut mini-core collection with control cultivars Gangapuri, M 13, ICGS 44 and ICGS 76 in augmented designed experiments during 2006-07 post-rainy and 2007 rainy seasons at ICRISAT Patancheru. ICGs 14482, 2772, 5286, 5891, 6766, and 875 produced 1.70 to 1.91 t ha<sup>-1</sup> in comparison to Gangapuri (1.13 t ha<sup>-1</sup>), M13 (1.28 t ha<sup>-1</sup>), ICGS 44 (1.66 t ha<sup>-1</sup>), and ICGS 76 (1.64 t ha<sup>-1</sup>) during 2006-07 post-rainy season. ICGs 12672, 6766, 12276, 5286, and 10185 were the five best accessions with greater pod

yield (1.61 to 1.91 t ha<sup>-1</sup>), higher 100-seed weight (70.9 to 81.1g), and very good shelling turn over (70.5 to 71.5%) in comparison to 47.9 to 70.0 g 100-seed weight and 68.7 to 72.1% shelling % in control cultivars. Data compilation for 2007 rainy season is in progress. We also evaluated 25 large-seeded groundnut accessions which were identified in mini-core collection during 2007 rainy season. Data compilation is in progress.

The mini-core collection of groundnut was also evaluated at Durgapura in Rajasthan and Raichur in Karnataka, Aliyarnagar in Tamil Nadu and Jalgaon in Maharashtra. ICGs 9905, 10185, 11426, 13099, and 14475 (1.94 to 2.35 t ha<sup>-1</sup>) were the best five mini-core accessions which produced greater pod yield than all the four control cultivars (Gangapuri (1.20 t ha<sup>-1</sup>), ICGS 44 (1.07 t ha<sup>-1</sup>), ICGS 76 (1.38 t ha<sup>-1</sup>), and M 13 (1.42 t ha<sup>-1</sup>) at Raichur. A total of 43 (22-26 days) accessions flowered earlier than the earliest control Gangapuri (27 days) at Raichur. ICG 13856, 13858, 1415, 2106, and 6888 flowered in 22-23 days. Similarly ICGs 5195, 442, 4684, 2773, and 4543 (75-79%) had higher shelling percentage than all the four control cultivars (65.0 to 67.5%). ICGs 11109, 9777, 9961, 9037, 7243, and 8760 were identified as having combined resistance to late leaf spot (LLS) (1%) and rust (1%) in comparison of M 13 (3% each), ICGS 76 (3.4% LLS; 2.4% rust), ICGS 44 (4% LLS; 3% rust) and Gangapuri (6.5% LLS ; 4% rust). ICGs 14466, 875, 1668, and 928 (1% BND) were identified as resistant to BND in comparison to 4-7% BND in all the control cultivars at Raichur. Data analysis for Durgapura is in progress.

S Vijayakumar (Raichur), RV Singh (Durgapura),  
HD Upadhyaya and CLL Gowda

*Milestone C.4.1.2: Core collection of pearl millet evaluated in multilocations in India (HDU/CLLG/NARS, 2008)*

A part of pearl millet core collection consisting of 504 accessions and four control cultivars were evaluated at three locations, ie, All India Coordinated Pearl Millet Improvement Project, Mandor, Jodhpur, Agricultural Research Station (Rajasthan Agricultural University) Durgapura, Jaipur, Rajasthan and at Gujarat Agricultural University, Jamnagar, Gujarat during 2006 rainy season. Promising accessions for seed yield potential were IPs 17350, 3150, 6769, and 17862 at Mandor and IPs 17945, 7095, 12591, 3163, and 12310 at Durgapura. Similarly, promising accessions for green fodder yield at Mandor were IPs 15304, 3616, 6125, 6148, and 5666; at Durgapura were IPs 13885, 6146, 6396, 15257, 3382, and 19299; and at Jamnagar were IPs 6897, 6396, 3529, and 3749. A wide range for productive tillers was observed at Mandore (1-7), Durgapura (1-4), and Jamnagar (1-3).

IS Khairwal (Mandor), CJ Dangaria (Junagadh),  
Sri Kant (Jaipur), HD Upadhyaya and CLL Gowda

Sixty-five accessions of finger millet mini-core collection were evaluated with five control cultivars at Kolhapur in Maharashtra. IEs 3077 and 3470 (2.16 to 2.24 t ha<sup>-1</sup>) had greater grain yield than all the five control cultivars (1.08 to 1.86 t ha<sup>-1</sup>).

Associate Director of Research (Mahatma Phule Krishi Vidyapeeth),  
HD Upadhyaya and CLL Gowda

*Milestone C.4.1.3: Reference sets of chickpea and sorghum phenotyped for agronomic traits (HDU/CLLG/CTH/BVSR, 2008)*

#### **Phenotyping chickpea reference set for yield and agronomic traits**

300 accessions of chickpea reference set were evaluated with desi (Annigeri, G 130, and ICCV 10) and two kabuli (L 550 and KAK 2) control cultivars in an augmented design experiment. Among desi types, 24 accessions produced higher seed yield (3.05 to 4.17 t ha<sup>-1</sup>) than Annigeri (3.03 t ha<sup>-1</sup>), G 130 (2.45 t ha<sup>-1</sup>), and ICCV 10 (2.06 t ha<sup>-1</sup>). ICCs 13892, 2263, 15868, 1180, and 6802 (3.68 t ha<sup>-1</sup>) were the best five high yielding accessions among desi types. Among kabuli types 35 accessions (2.18 to 4.18 t ha<sup>-1</sup>) produced higher seed yield than L 550 (2.10 t ha<sup>-1</sup> seed yield and 20.5 g 100-seed weight) and KAK 2 (1.78 t ha<sup>-1</sup> seed yield and 38.3 g 100-seed weight). ICCs 8155, 12328, and 16654 and IG 6905 were the best large-seeded kabuli accessions (39.1 to 43.9 g) combined with higher seed yield (2.40 to 3.48 t ha<sup>-1</sup>).

HD Upadhyaya, N Lalitha and CLL Gowda

*Output target C.5: Mini-core and reference collections of staple crops and small millets evaluated to identify trait specific germplasm (2012)*

**Activity C.5.1: Evaluate mini-core and reference collections for resistance to important biotic stresses**

### **Core and mini core collections**

To enhance the utilization of large germplasm collections in crop improvement programs diversity using phenotypic traits was studied in the entire collection (about 17, 000 accessions) and a core collection (10% of entire collection) consisting 1,956 accessions and representing chickpea diversity was developed at ICRISAT. The size of core collection was still unwieldy for convenient exploitation by the crop improvement scientists and to overcome this, a mini core collection (10% of core, 1% of entire collection) consisting 211 accessions representing the diversity of collection was developed.

### **Composite collection and reference set**

Composite collection of chickpea consisting 3,000 accessions was developed based on available phenotypic, characterization, evaluation, geographic origin, and taxonomic data under Generation Challenge Program (GCP). The composite collection included 2271 cultivated (including 1956 core collection accessions) and three wild genotypes from ICRISAT and 709 cultivated and 17 wild accessions from ICARDA representing the diversity of two global collections. The composite collection was molecularly profiled using 50 SSR markers in collaboration with ICARDA (ICRISAT 35 SSR, ICARDA 15 SSR) to discern the diversity and population structure.

### **Activities Exemplar**

One of the 2012 Output Targets (2012 2.C.5) declared is “Mini core and reference of staple crops and small millets evaluated to identify trait specific germplasm”. This results in several activities which were reported, with internal milestones in Centre’s Archival Report for 2007 (available at [www.icrisat.org](http://www.icrisat.org)). Several other activities and milestones also contributing to this Output Target are reported elsewhere in the said report.

### **The activities of Output target 2.C.5**

- Evaluate mini-core and reference collections for resistance to important biotic stresses
- Evaluate mini-core and/or reference sets for important abiotic stresses
- Investigation of genetic diversity of chickpea and groundnut reference sets and assessing its relevance with drought avoidance root traits

### **2007 Milestones**

- Groundnut, pigeonpea and chickpea mini-core sets screened for salinity tolerance
- <sup>13</sup>C in chickpea analyzed at JIRCAS
- Trait specific germplasm of chickpea multiplied for distribution to partners on request

### **2008 Milestones**

- Mini-core and reference collections of chickpea germplasm evaluated for resistance to AB, BGM, wilt, collar rot and dry root rot under controlled environment and field
- Chickpea reference set phenotyped for root traits in PVC cylinders (120cm height)
- Chickpea reference set field evaluated for drought response
- Chickpea mini-core salinity evaluation data analyzed
- Chickpea reference set genotyped with 100 SSR markers
- Reference set of chickpea multiplied for distribution to partners on request

### **2009 Milestones**

- Ten chickpea lines identified, which showed steady high water use efficiency (WUE) as well as high yielding in two locations

### **2010 Milestones**

- Reference sets of chickpea, pigeonpea, and groundnut evaluated for salinity
- Reference set of chickpea (300 accessions) utilized for candidate gene diversity for mining the drought tolerant alleles

### **2011-2012 Milestone**

- Diversity analyzed for the molecular markers and markers associated with root traits identified

The report for 2007 internal milestones provides detailed information on the progress towards achieving this Output Target. Due to greatly reduced size and availability of a large amount of diversity, the mini core collection of chickpea is becoming popular with national programs scientists in identifying trait specific germplasm for use in

their breeding programs. The chickpea mini core was evaluated at ICRISAT Centre and by NARS partners at different locations in India, Japan, Canada, Mexico and Ukraine. These evaluations have resulted in identifying several trait specific germplasm for agronomic traits, resistant sources for important pests and diseases and drought and salinity. These results have been published in several refereed journal articles and in the Archival Reports.

In collaboration with JIRCAS, a significant correlation between the water use efficiency (WUE) and  $\Delta^{13}\text{C}$  (leaf carbon discrimination) of chickpea has been shown, which means that the estimation of WUE by using  $\Delta^{13}\text{C}$  technique is possible. Currently,  $\Delta^{13}\text{C}$  analysis for chickpea mini core collection is ongoing to evaluate the genetic diversity on WUE.

Using 50 SSR markers data on composite collection, a reference set consisting of 300 genetically most diverse accessions using simple matching distance matrix was selected. The reference set captured 1360 (78%) of the 1741 alleles detected in the composite collection, and possessed high gene diversity (0.540 to 0.999).

Evaluation of reference collection for resistance to pod borer, *Helicoverpa armigera*, using detached leaf assay suggested that there is considerable variation in the reference collection for resistance/susceptibility. Seed multiplication of chickpea reference set accessions and trait specific germplasm identified during these is in progress.

*Milestone C.5.1.1: Mini-core and reference collections of chickpea germplasm evaluated for resistance to AB, BGM, wilt, collar rot and dry root rot under controlled environment and field (SP/HDU/PMG/RKV/CLLG, 2008)*

**Evaluation of selected chickpea composite set for resistance to Fusarium wilt, Ascochyta blight, Botrytis grey mold, dry root rot and collar rot:** Two hundred and fifty new germplasm accessions from composite set were evaluated for resistance to Fusarium wilt (FW), Ascochyta blight (AB), Botrytis gray mold (BGM), dry root rot (DRR) and collar rot (CR) following standardized evaluation techniques for individual diseases at ICRISAT-Patancheru. Incidence of FW and CR was recorded as percentage of mortality and severities of AB, BGM and DRR were scored on 1-9 rating scale.

Of the 250 entries evaluated for FW under artificial epiphytotic conditions in wilt sick plot at ICRISAT, Patancheru; only one accession ICC 2072 was found resistant (<10%) and two accessions ICCs 2083, 2096 had moderate resistance (10.1 to 20%) reaction. Eight accessions, ICCs 643, 1052, 1069, 1093, 1903, 1915, 2114, 2142 were found moderately resistant (3.1 to 5 rating on 1-9 scale, where 1 = no symptoms and 9 = >75% mortality) to AB under controlled environment. Twenty nine accessions were identified moderately resistant (3.1 to 5 rating on 1-9 scale) to BGM under controlled environment. Of the 250 accessions, 2 accessions ICCs 562, 1600 were found resistant (<3 rating on 1-9 rating scale) and 76 accessions had moderate resistance (3.1 to 5 rating on 1-9 scale) to DRR in blotter paper technique under laboratory conditions. However, all the 250 accessions were found highly susceptible to collar rot in glasshouse.

S Pande, M Sharma, HD Upadhyaya and CLL Gowda

Evaluated 211 accessions of chickpea mini-core collection along with resistant and susceptible control cultivars for ascochyta blight and botrytis gray mold at Punjab Agricultural University, Ludhiana. All the accessions were scored based on their reaction to each disease on 1 (asymptomatic) to 9 (highly susceptible) score. ICC 8522 and ICC 1052 were resistant (3 score) and ICCs 4182, 7255, and 13524 were moderately resistant (4-5 score) to ascochyta blight. ICC 15610 and 15612 were moderately resistant (5 score) to botrytis gray mold.

Livinder Kaur, S Pande, HD Upadhyaya and CLL Gowda

*Milestone C.5.1.2: Mini-core and reference collections of pigeonpea germplasm evaluated for resistance to wilt and sterility mosaic diseases under controlled environment and field conditions (SP/PLK/FW/HDU/KBS, 2008)*

**Evaluation of selected pigeonpea mini-core accessions for combined resistance to Fusarium wilt and Sterility Mosaic (SM):** Twenty eight mini-core accessions promising to wilt and SM were tested for combined resistance to both these diseases in wilt and SM sick plot under artificial epiphytotic conditions following standard field evaluation techniques. Two accessions, ICPs 11015 and 14819, showed combined resistance to wilt and SM, while seven accessions, ICPs 7869, 8152, 9045, 11230, 11910, 13167, 13304 were found asymptomatic (0%) and 13 accessions, ICPs 6739, 8152, 9045, 11230, 11281, 11320, 11823, 13304, 13579, 14368, 14801, 14976, 15049 (<10%) were found resistant to SM.

S Pande, M Sharma and HD Upadhyaya



*Milestone C.5.1.3: Mini-core collection of pigeonpea germplasm evaluated for resistance to Helicoverpa (HCS/HDU/KBS, 2009)*

**Evaluation of mini-core collection of pigeonpea for resistance to *Helicoverpa*:** Mini-core collection of pigeonpea is being evaluated for resistance to pod borer, *H. armigera*. Each genotype has been planted in 2 row plots, 2 m long. There are two replications in a randomized complete block design. Data will be recorded on genotypic resistance to *H armigera* on a 1 – 9 scale (1 = <10% pods damaged, and 9 = 80% pods damaged) at maturity.

HC Sharma and HD Upadhyaya

*Milestone C.5.1.4: Mini-core collection of groundnut evaluated for resistance to seed infection by Aspergillus flavus and aflatoxin contamination (FW/PLK/HDU, 2009)*

Groundnut mini-core collection consisting 184 accessions and four control cultivars were planted in two replications with RBD in the AF sick plot during 2007 rainy season. Highly toxigenic strain (AF 11-4) of *A. flavus* multiplied on maize/sorghum/pearl millet seed was broadcasted in the field before sowing, followed by row application of inoculum at fortnight intervals starting from 25 days after sowing. Terminal drought was imposed 30 days before harvest to facilitate the seed infection and aflatoxins contamination. Harvesting was done by up-rooting the plants and produce dried under sunlight for 5-7 days before the pods were stripped. Post-harvest sampling for *A. flavus* seed infection aflatoxin analysis is in progress and the results are awaited.

F Waliyar and HD Upadhyaya

*Milestone C.5.1.5: Sorghum mini-core set evaluated for resistance to grain mold and anthracnose (RPT/RS/HDU, 2010)*

**Grain mold resistance in sorghum mini-core collection:** Two-hundred sixty-five sorghum mini-core lines available in the ICRISAT genebank were evaluated in the sorghum grain mold nursery. The germplasm lines were grown in single rows of 2m/line along with susceptible and resistant checks after every 10-test lines in the grain mold nursery. Sprinkler irrigation was provided twice a day for 30 minutes each on rain-free days from flowering to physiological maturity to provide high humidity (>90% RH) essential for mold development. The grain mold scores were recorded at physiological maturity using a 1 to 9 scale, where 1 = no mold infection (highly resistant) and 9 => 75% molded grains on a panicle (highly susceptible). Grain mold was scored only in 155 lines and the remaining 110 lines were late flowering. The mean grain mold scores on test lines ranged from 1.0 to 9.0 compared to 2.0 to 3.4 scores on resistant checks (IS 8545) and 8.8 to 9.0 on the susceptible checks (SPV 104 and Bulk Y). Results indicated that 10 (IS 608, IS 1212, IS 1233, IS 2413, IS 3121, IS 12697, IS 12804, IS 13264, IS 602 and IS 603) of the 155 lines were highly resistant (score 1.0), 56 resistant (≤3.0 score), 31 moderately resistant (3.1-5.0 score) and the remaining 48 lines were susceptible/highly susceptible to grain mold.

RP Thakur, R Sharma and HD Upadhyaya

*Milestone C.5.1.6: Pearl millet core set evaluated for resistance to downy mildew and rust (RPT/RS/HDU, 2011)*

No report for 2007

*Milestone C.5.1.7: Finger millet core set evaluated for resistance to foliar and neck blast (RPT/RS/HDU/CLLG, 2010)*

No report for 2007

*Milestone C.5.1.8: Foxtail core set evaluated for resistance to blast disease (RPT/RS/HDU/CLLG, 2012)*

No report for 2007

*Milestone C.5.1.9: Identification and evaluation of trait specific germplasm in finger millet and foxtail millet core collections (CLLG/HDU, 2008)*

Using the characterization data over the years, we selected 40 promising high yielding accessions of finger millet and foxtail millet. These accessions were planted in 2007 rainy season in Randomized Complete Block Design. Data compilation is in progress.

CLL Gowda and HD Upadhyaya

### **Activity C.5.2: Evaluate mini-core and/or reference sets for important abiotic stresses**

*Milestone C.5.2.1: Groundnut, pigeonpea and chickpea mini-core sets screened for salinity tolerance (VV/HDU/CLLG/PMG/RKV/KBS, 2007)*

**Chickpea screening:** After two years of screening for salinity tolerance, based on the seed yield under control and saline conditions (80 mM NaCl solution in sufficient amount to saturate the Vertisol used), a set of 108 contrasting genotypes were identified (28 sensitive and 80 tolerant). The most contrasting from these 108 are published in Vadez et al. 2007, *Field Crops Research* 104:123-129. The 108 most contrasting genotypes were screened again in 2006-07 under black and red soil conditions and saline conditions. The performance under saline Alfisol matched the performance under saline Vertisol ( $R^2 = 0.33$ ). The same set was also screened under boron (15 ppm), and boron + salt (10 ppm boron + 80 mM NaCl) and also revealed that some of the lines had fairly good boron tolerance, although all the genotypes appeared to be fairly severely affected by the boron treatment. From that set of genotypes, 55 were sent to Australia for further testing.

From the screening performed under the conditions at Patancheru, characterized by a short season length for chickpea, there was a negative correlation between the duration of the growth cycle and salinity tolerance. The fact that most late maturing genotypes turned out to be sensitive in a short season length environment may be related to the season length itself. Therefore, it is now critical to test these contrasting genotypes in environments enjoying a longer duration. We are currently multiplying seeds from 20 accessions, for these to be tested in several locations in 2008-09. The result of the work on the salinity screening of the mini-core collection has been published in *Field Crops Research*.

#### **Groundnut screening:**

The groundnut screening for salinity tolerance from 2006, in which a six-fold range of variation was found, was repeated at same time in 2006-07, during a different season. Planting was done in mid-November and harvest was completed in April. Same as the 2006 screening, plants were cultivated under saline and control conditions until maturity and we could therefore assess the yield. In the screening, there was a five-fold range of variation in the seed yield under salt stress (125 mM treatment, compared to 100 mM in 2006, equivalent to 1.46 g kg<sup>-1</sup> soil), ranging from about 6.5 g pod DW pot<sup>-1</sup> to about 35 g pod DW pot<sup>-1</sup>. We analyzed the 2006 and 2006-07 data together and found large genotype-by-environment interaction. This was expected because the light, temperature and humidity conditions under which the accessions were tested varied a lot. There was no relation between the performance under salt stress in the previous season, in which most of the growth occurred during the summer season (planting was done in April), and this one which was grown during the winter season. In fact, in 2006, the pod weight under salinity reached hardly 33% of that under control conditions, whereas in 2006-07, the pod weight was above 50% of that under control conditions, even if the salt treatment in 2006-07 was 25% higher than in 2006. This may largely explain the large G x E interaction. The combined analysis of data revealed a six-fold range of difference for seed yield under salt stress ranging from about 3.0 g pod DW pot<sup>-1</sup> to about 20 g pod DW pot<sup>-1</sup>. A set of 30 consistently contrasting genotypes were identified, 16 sensitive and 14 tolerant, and used for diversity analysis. These genotypes were screened with 21 markers to assess their diversity at the DNA level, and then to choose the most suitable parents for crossing. Out of these, 18 showed polymorphisms between the lines. Interestingly, we found that genotypes JL 24 (sensitive) contrasted with ICG (FDRS) 10 (tolerant) across seasons. An RIL population from these 2 parents is being developed for ELS, LLS and rust and is now at F<sub>5</sub> generation. Genotype CSMG 84-1 (sensitive) also contrasted with genotypes ICGS44 and ICGS 76 (tolerant). RILs population ICGS 44 x CSMG 84-1 and ICGS76 x CSMG 84-1 have been developed for TE and are now at F<sub>8</sub> stage. These 3 populations can be potentially used to phenotype for salt tolerance and possibly to identify QTLs for salinity tolerance.

#### **Pigeonpea screening:**

The pigeonpea mini-core collection, along with a set of 68 accessions of wild pigeonpea relative from 7 different species, and a set of 68 accessions of cultivated pigeonpea and possibly originating from salinity affected areas (based on latitude, longitude and location data of original collection) has been screened. Data from the 2005 experiment were processed and analyzed and published in the *E-Journal of SAT Agriculture Research*. In this evaluation, we have assessed the morphological and physiological variation in pigeonpea for

salinity tolerance in 287 genotypes altogether. We found a large variation in the salinity susceptibility index (SSI) and the percent relative reduction (RR %) in both cultivated and wild accessions. The amount of Na<sup>+</sup> accumulation in shoot showed that more tolerant cultivated materials accumulated less Na<sup>+</sup> in shoot. Such relation was not true for wild species. Wild species *C. acutifolius*, *C. cajanifolius* and *C. lineatus* were mostly sensitive, whereas *C. platycarpus*, *C. scarabaeoides* and *C. sericeus* provided good sources of tolerance. *C. scarabaeoides* also provided a large range of sensitive materials. The mini-core collection of pigeonpea provided a large range of variation for salinity tolerance. Among the tolerant genotypes, there were a large number of tolerant accessions originating from Bangladesh. A repeat of that pigeonpea screening has been performed in 2007 and data would be analysed.

V Vadez, L Krishnamurthy, RK Varshney and HD Upadhyaya

*Milestone C.5.2.2: Chickpea mini-core salinity evaluation data analyzed (VV/HDU, 2008)*

The results of the work on the salinity screening of the mini-core collection have been published (Vadez et al. 2007. Field Crops Research 104:123-129). The first set of data has been posted on ICRISAT's data repository system.

V Vadez and L Krishnamurthy

*Milestone C.5.2.3: Sorghum mini-core and pearl millet reference set screened for salinity tolerance (VV/HDU/CTH/KNR, 2008)*

The CIRAD sorghum collection (165 entries), mapping population parents for salinity tolerance (10) and stay green traits (13) and some of the contrasting breeding lines that needed further confirmation (36) have been tested for their response to salinity by irrigating with saline solution in two doses to an equivalent of 200 mM NaCl solution irrigation to fully saturate 9 kg of soil. A non-saline control was also planted as a treatment. A wide range of variation for both shoot biomass production as well as for the grain yield under saline condition was observed. The ability to produce high shoot biomass under salinity also helped in high grain yield production in some accessions. The top ten of the CIRAD collection accessions that produced significantly high shoot biomass and shoot biomass ratio were IS 10876, IS 30030, IS 11026, IS 26554, IS 29691, IS 10882, IS 26041, IS 33261, IS 3780 and IS 20706. The ten accessions that produced significantly lower shoot biomass and shoot biomass ratio were IS 12531, IS 8882, IS 8685, IS 19847, IS 2416, IS 2814, IS 33116, IS 30417, IS 3971 and IS 10194. The top ten accessions that produced significantly high grain yield and grain yield ratio were IS 27490, IS 22282, IS 31681, IS 26554, SSM 501, IS 20351, IS 30030, IS 22294, IS 31559 and IS 24139 and the bottom ten accessions with poor grain yield or grain yield ratio were IS 8685, IS 10882, IS 19847, IS 9303, IS 2416, IS 16545, IS 29375, IS 33116, IS 3073 and IS 23645.

Among the breeding the lines CSV 15, ICSB 699, A 2267-2, ICSR 93024-1, SP 39262, ICSV 12, GD 65008 (brown), SPV 1022, ICSB 707 and SP 47519 were tolerant entries for shoot biomass production and NTJ 2, ICSV 93046, ICSV 112, CSV 15, GD 65008 (brown), SPV 1022, SP 47519, ICSB 707 and SP 39105 were tolerant for grain yields.

The tolerant response of mapping population parents E 36-1, PB 15881-3, BTX 623 and IS 18551 have been confirmed for salt-tolerance in relation to the performance of IS 9830, N13, PB 15520 and B 35. The salinity response of the stay green entries for both shoot as well as grain yield of ISIAP Dorado, IDSG 06146 and IDSG 06177 have been good compared to that of B 35, IDSG 06151 and IDSG 06169.

V Vadez, L Krishnamurthy, HD Upadhyaya,  
CT Hash and KN Rai

*Milestone C.5.2.4: Groundnut and pigeonpea mini-core sets salinity evaluation data analyzed (VV/HDU/RKV, 2009)*

Compilation of data is on the way for publication in refereed journal. The data should also soon be posted on ICRISAT's data repository system.

V Vadez and L Krishnamurthy

*Milestone C.5.2.5: Reference sets of chickpea, pigeonpea, and groundnut evaluated for salinity (VV/HDU/RKV, 2010)*

No report for 2007

### **Activity C.5.3: Evaluate groundnut and sorghum mini-core and/or reference sets for transpiration efficiency (TE) and root traits**

*Milestone C.5.3.1: Groundnut mini-core set screened for TE (VV/HDU/RKV/CLLG, 2008)*

#### **Evaluation of groundnut mini-core for transpiration efficiency**

A first screening of the mini-core has been performed in 2006, and revealed a four-fold range of variation in TE values. Details of this screening are reported in 2006 Archival Report. The screening was repeated in 2007. Preliminary analysis of data reveals a large G x E interaction for TE under water stress conditions, which was due to the fact that the experiment was carried out late into the summer season under fairly high temperatures. However, the pooled analysis revealed a large range of variation for TE, with genotypes having consistently low and high TE levels across the seasons. Data still need to be analyzed for the well-watered treatment. A repeat of the mini-core is currently on-going, under environmental conditions that will be again different from the previous two screenings. The main purpose is to identify a set of genotypes with high TE levels across conditions that vary a lot for the vapor pressure deficit (VPD).

V Vadez, L Krishnamurthy and HD Upadhyaya

*Milestone C.5.3.2: Sorghum mini-core (or reference) set screened for TE (VV/HDU/CTH/BVSR, 2009)*

No report for 2007

*Milestone C.5.3.3: Groundnut mini-core screened for root traits (VV/HDU/RKV/CLLG, 2010)*

Following the successful preliminary trials to assess water uptake by plants in a real soil profile mimicked by a long PVC tube, reported in the previous archival report, the rain-out-shelter (ROS) of ICRISAT has been modified into a root study facility in 2007 (Figure 8). Four large trenches have been dug and cemented. Each trench should accommodate about 700 cylinders (1.2 m long and 20 cm diameter), each collared in a way that they can be lifted up and weighed using a hanging scale. This set up allows for the evaluation of about 300 accessions in two treatments and 3 replications. This system will be used to assess the range of variation for the volume of water uptake upon exposure to water deficit, and also to the kinetics of water uptake under water deficit. These traits will be compared to those under well-watered conditions. This trial is planned for 2008.



**Figure 8. Modified root study facility for screening groundnut germplasm accessions**

V Vadez and L Krishnamurthy

*Milestone C.5.3.4: Sorghum mini-core (or reference set) screened for root traits (VV/HDU/CTH/BVSR, 2011)*

No report for 2007

*Milestone C.5.3.5: <sup>13</sup>C in chickpea analyzed at JIRCAS (JK/HDU/LK/PMG/IIPR-Kanpur/JIRCAS-Japan, Annual)*

In collaboration with Japan International Research Center for Agricultural Science (JIRCAS), a significant correlation between the water use efficiency (WUE) and  $\Delta^{13}\text{C}$  (leaf carbon discrimination) of chickpea has been

shown, which means that the estimation of WUE by using  $\Delta^{13}\text{C}$  technique is possible. Currently,  $\Delta^{13}\text{C}$  analysis for chickpea mini-core collection is ongoing to evaluate the genetic diversity on WUE.

J Kashiwagi, HD Upadhyaya, L Krishnamurthy, PM Gaur,  
IIPR-Kanpur and JIRCAS-Japan

*Milestone C.5.3.6: Ten chickpea lines identified, which showed steady high water use efficiency (WUE) as well as high yielding in two locations (JK/HDU/LK/PMG/IIPR-Kanpur/JIRCAS-Japan, 2009)*

No report for 2007

**Activity C.5.4: Investigation of genetic diversity of chickpea and groundnut reference sets and assessing its relevance with drought avoidance root traits**

*Milestone C.5.4.1: Chickpea reference set phenotyped for root traits in PVC cylinders (120cm height) (JK/HDU/LK/RKV/NL, 2008)*

No report for 2007

*Milestone C.5.4.2: Chickpea reference set field evaluated for drought response (JK/LK/HDU/NL, 2008)*

No report for 2007

*Milestone C.5.4.3: Chickpea reference set genotyped with 100 SSR markers (HDU/RKV/JK/LK/SC/NL, 2008)*

**Genotyping chickpea reference set with additional markers**

To find out additional SSR markers, we screened 195 SSR markers (22 markers from Huttel et al. 1999 and 173 markers from Winter et al. 1999) on 2 diverse genotypes and identified 100 SSR markers. The Reference set of the chickpea is being genotyped with the selected 100 SSR markers, 18 from Huttel et al. 1999 and 82 from Winter et al. 1999 by using ABI-3130xl automatic DNA sequencer (PE Applied Biosystems, Foster City, California). The electrophoretic data were exported to the Genescan 3.1 software (PE- Applied Biosystems, Foster City, California) to size peak patterns, using the internal LIZ-500 size standard and GENOTYPER 3.1 (PE Applied Biosystems, Foster City, California) for allele calling, and further the analysis is in progress.

N Lalitha, HD Upadhyaya, RK Varshney,  
J Kashiwagi and L Krishnamurthy

*Milestone C.5.4.4: Groundnut reference set phenotyped for traits associated with drought resistance (VV/HDU/RKV, 2009)*

The groundnut reference set will be evaluated for TE during the 2007 post-rainy season (Oct-Dec 07), whereas the evaluation for water uptake in lysimeters will be undertaken in early 2008 (Jan-Apr 08).

V Vadez, L Krishnamurthy and HD Upadhyaya

*Milestone C.5.4.5: Groundnut reference set genotyped with 100 SSR markers (HDU/RKV/DH, 2010)*

No report for 2007

*Milestone C.5.4.6: Reference set of chickpea (300 accessions) utilized for candidate gene diversity for mining the drought tolerant alleles (RKV/HDU/JK/DH/PMG, 2010)*

Under an Allelic Diversity on Orthologous Candidate genes (ADOC) sponsored by Generation Challenge Programme, the CAP2 gene, the homolog for DREB2A and its promoter sequence have been identified. In the first instance, these candidate gene sequences are being targeted to screen the set of 300 accessions of chickpea reference collection (see Output Target D.3).

RK Varshney, S Nayak, HD Upadhyaya and DA Hoisington

*Milestone C.5.4.7: Diversity analyzed for the molecular markers and markers associated with root traits identified (HDU/JK/RKV/LK/SC/NL, 2011)*

No report for 2007

*Milestone C.5.4.8: Diversity analyzed for the molecular markers and markers associated with drought traits identified (HDU/RKV/DH, 2012)*

No report for 2007

**Output target C.6: Germplasm sets evaluated for utilization in Africa (2009)**

**Activity C.6.1: Evaluation (field test) of the global pearl millet core set at Sadore, Niger**

*Milestone C.6.1.1: M Sc thesis on evaluation of the pearl millet core set at Sadore, Niger, completed and data available in Excel format (BH/HDU, 2007)*

#### **Evaluation of pearl millet core collection**

The 504 accessions of global pearl millet core collection were characterized in a replicated field trial at ICRISAT-Sadore (Niger) in the rainy season 2006 for 6 qualitative and 21 quantitative traits. The study revealed large variation for nearly all traits, indicating the potential of the core collection to provide source materials for broadening the genetic base of breeding populations. However, a large part of the collection (mainly Asian materials) was not adapted to the test site, suffering from insect attack, downy mildew, smut and ergot infestation. Only two accessions were significantly superior over the local check, raising the question whether adapted West African materials were appropriately represented in the collection, and/or whether the materials suffered from a certain degree of inbreeding depression due to possibly too low effective population size during collection and/or regeneration/multiplication of the seed.

Principal component analysis revealed 3 axes explaining 63% of the total variation, and clearly separated the materials according to geographic origin. Further sources of separation between the accessions were grain weight, days to 50% flowering, panicle length and leaf length.

The following traits were found to be rare in this subset of the global core: oblanceolate, spindle and globose panicle shape; panicles with long bristles; purple, yellow, ivory and orange-white seed color; and elliptical seed shape. Club and dumbbell panicle shapes as well as purplish black seed color were missing in the collection. The total pearl millet collection should be examined for representation of these traits to check whether there is need to carry out a complementary collection.

A German M. Sc. student was involved in the work and her M. Sc. thesis is available.  
BIG Haussman

**Activity C.6.2: Characterize core collection of finger millet and identify materials for regional evaluation**

*Milestone C.6.2.1: Core collection of finger millet characterized for morpho-agronomic and end use traits (MAM/SGM/HDU, 2007)*

#### **Characterization of finger millet core collection**

The 504 accessions of finger millet core collection from Africa (Kenya-55, Malawi-24, Nigeria-5, Uganda-70, Zambia-18, Zimbabwe-88), Asia (India-147, Nepal-66), Europe (Italy-3, UK-3) and USA (5) was obtained from ICRISAT genebank in India and evaluated for 15 quantitative traits at Alupe and Kiboko in Kenya in 2005 and 2006. All data analyses were done using Genstat 10.0 statistical software. Data were subjected to ANOVA and only variables showing significant differences were used for the multivariate analysis (PCA and Hierarchical Cluster analysis) to determine patterns of variation and major traits contributing to the delineation. Wide ranges were recorded for days to flowering, plant heights, fingers per panicle, finger length, finger width, number of productive tillers and grain yield. Differential adaptation to environments in the germplasm was observed whereby there was wide range in variability in days to flower at Alupe (49-125 days,) than at Kiboko (49-92 days,). However, most accessions flowered earlier at Alupe (mean 67 days) than at Kiboko (mean 69 days). Most accessions were taller at Kiboko (mean 74.4 cm) than at Alupe (mean 57.7cm). The earliest accessions at both locations were from India and Nepal whereas accessions from Malawi, Nigeria and Zambia were the latest. There was positive correlation between finger width and grain yield. However, high negative correlations were recorded between days to flower and neck and finger blast, plant height and grain yield. Thus early maturing accessions were very susceptible to blast. The diversity in blast reaction indicates potential to select for blast resistance in the germplasm for hybridization programs. There was distinct variability in each country's

germplasm for grain yield potential and although post-flowering moisture stress affected grain yield expression at Alupe, the general trends in yield potential were similar at both locations with highest mean yields recorded in Indian, Kenyan and Ugandan germplasm. The high scope for genetic improvement of finger millet was evident from the high variability observed between and within countries of origin for most of the quantitative traits recorded. These preliminary results will be further strengthened by understanding the genetic variability and also by incorporating qualitative data to fully discern the variability in this germplasm.

MA Mgonja, E Manyasa, E Muange and J Kibuka

*Milestone C.6.2.2: Promising and adaptable materials identified and distributed and evaluated in regional finger millet trials in the ESA (MAM/SGM, 2008)*

No report for 2007

Activity C.6.3: Characterize a sorghum core collection from five African Bio-fortified Sorghum target for diversity in micro nutritional traits

*Milestone C.6.3.1: Diversity for micronutrients content in a sorghum core collection from at least 2 ABS target countries established (MAM/SGM/HDU, 2008)*

No report for 2007

#### **Activity C.6.4: Evaluate groundnut mini-core collection/wild species in ESA**

*Milestone C.6.4.1: Mini-core collection of groundnut evaluated for agronomic traits at different locations in ESA (ESM/HDU, 2008)*

##### **Evaluation of groundnut mini-core collection**

One hundred eighty-four groundnut accessions of mini-core collection and four control cultivars from the genebank alongside four local checks were planted in a replicated trial in three nurseries at Chitedze Research Station, Malawi. The first being under normal field conditions (or wide adaptation) the second being under high rosette disease pressure and the third under high early leaf spot disease pressure. All the three nurseries were planted in December 2006. Potential sources of resistant lines to groundnut rosette disease and early leaf spot were identified. Three lines, ICG 6888, ICG 14705 and ICG 13099 recorded resistance (0-11%) under high rosette disease pressure compared to susceptible checks which recorded over 90% infection. The disease reaction of the three lines were significantly ( $p < 0.05$ ) similar to the resistant released checks; ICG 12991 and ICGV-SM 90704 which recorded 0%. The rest of the entries attained rosette disease incidences ranging from 35-100%. Compared to the control check JL 24 (328 kg/ha<sup>-1</sup>), the yield potential of resistant test lines ICG 14705 (703 kg/ha<sup>-1</sup>) and ICG 13099 (592 kg/ha<sup>-1</sup>) out yielded the local check by 214 and 180%, respectively, under high rosette disease pressure. Resistance to early leaf spot was observed in ICG 6022 which attained a disease score of 2 on a 1- 9 scale at 100 days after emergence, compared to susceptible check score of 8.

ES Monyo, H Charlie and HD Upadhyaya

*Milestone C.6.4.2: Wild Arachis evaluated for target traits (GRD, ELS, aflatoxin resistance) at hotspot locations in ESA (ESM/HDU, etc, 2009)*

No report for 2007

*Milestone C.6.4.3: Gene introgression carried out for foliar and viral disease resistance from wild Arachis germplasm into cultivated varieties (ESM/HDU, etc, 2010)*

No report for 2007

#### **Output target C.7: Trait specific germplasm of staple crops and small millets available for utilization (2009)**

**Activity C.7.1: Ensure availability of germplasm accessions for selected traits of staple crops and small millets to partners**

*Milestone C.7.1.1: Trait specific germplasm regenerated/multiplied for distribution to partners on request (HDU/CLLG/RPT-PQL/NBPGR, Annual)*

We regenerated various trait specific germplasm and mini-core collections in groundnut, chickpea, pigeonpea and sorghum for distribution to the partners.

**Groundnut:** Multiplied the seed of 184 accessions of global mini-core, 60 accessions of Asia mini-core, 24 chilling tolerant at germination, 14 bacterial wilt resistant, 21 early maturing, 18 drought tolerant and 60 high yielding combined with other traits of economic importance, and groundnut accessions for distribution to partners. In addition, we also regenerated the seed of salinity tolerant (6), aflatoxin resistant (5), high oleic/linoleic acid ratio (4), high oil content (7) accessions.

**Chickpea:** Multiplied the seed of 28 early maturing and 18 drought tolerant, 16 large-seeded kabuli, 39 high yielding combined with other traits of economic importance and 29 salinity tolerant accessions. Also multiplied the seed of high yield (39), resistant/tolerant to ascochyta blight (3), botrytis gray mold (55), wilt (67), dry root rot (5), *Helicoverpa* (7), drought (18), salinity (29), multiple resistance (31), chickpea accessions for distribution to partners.

**Pigeonpea:** Multiplied the seed of 54 accessions identified for high yield combined with other agronomic traits, early-maturity (20), salinity (5), sterility mosaic (28), wilt (8), phytophthora blight (78), multiple resistance (2).

**Sorghum:** Multiplied the seed of nine grain mold resistant accessions.

**Mini-core:** Multiplied the seed of chickpea, pigeonpea, and groundnut mini-core collections for distribution to partners.

HD Upadhyaya, CLL Gowda and RP Thakur

*Output target C.8: Germplasm reference collections available for utilization (2009)*

**Activity C.8.1: Ensure availability of reference collections of staple crops and small millets to partners**

*Milestone C.8.1.1: Germplasm accessions of reference collections regenerated/multiplied for distribution to partners on request (HDU/RPT/CLLG/NBPGR, Annual)*

Regeneration of chickpea and groundnut reference sets is in progress.

HD Upadhyaya, PM Gaur,  
V Vadez and DA Hoisington

*Output target C.9: Broadening the genetic base of legumes through wide crosses (2011)*

**Activity C.9.1: Broadening the genetic base of groundnut by creating tetraploid groundnut using wild *Arachis*, synthetic amphidiploids and/or other diverse germplasm.**

*Milestone C.9.1.1: Hybrids between A and B genome species made available (NM/HDU/DH, 2007)*

Seeds were obtained crossing four new combinations using A and B genome species (*A. trinitensis* ICG 14270 x *A. hoehnei* ICG 8190, *A. simpsonni* ICG 15004 x *A. batizocoi* ICG 8210, *A. digoi* ICG 4983 x *A. hoehnei* ICG 8190, *A. duranensis* ICG 8123 x *A. hoehnei* ICG 8190, *A. ipaensis* ICG 8206 x *A. duranensis* ICG 8123, *A. ipaensis* ICG 8206 x *A. duranensis* ICG 8123). The F<sub>1</sub> hybrids obtained were confirmed as true hybrids through molecular analysis. Seed set in F<sub>1</sub> hybrids was low and varied from 1-11. Selected diploid F<sub>2</sub> hybrids obtained crossing A and B genome *Arachis* species, generated in 2006, were confirmed as true hybrids through molecular analysis using SSR markers.

N Mallikarjuna, DA Hoisington and HD Upadhyaya

*Milestone C.9.1.2: Tetraploid hybrids between different genomes generated and skeletal map constructed (NM/RKV/HDU/DH, 2008)*

A total of 49 hybrids belonging to 5 combinations of A and B genome species (*A. valida* x *A. digoi*, *A. valida* x *A. duranensis*, *A. kempff-mercadoi* x *A. stenosperma*, *A. kempff-mercadoi* x *A. hoehnei*, and *A. batizocoi* x *A.*



*cardenasii*) were treated with colchicines to double the chromosome number. Eight plants belonging to all the 5 hybrid combinations had doubled chromosome number, which was confirmed through pollen diameter and cytological analysis, and the hybridity of the plants was confirmed through molecular analysis.

N Mallikarjuna, DA Hoisington and HD Upadhyaya

*Milestone C.9.1.3: Hybrids between cultivated groundnut and synthetic amphidiploids created, variation for different traits analyzed and molecular map constructed (NM/RKV/HDU/DH/FW/PLK, 2009)*

No report for 2007

*Milestone C.9.1.4: Develop hybrids between section Arachis and section Procumbentes and generate fertile backcross population and screen for desirable traits (NM/DH/HDU/FW/PLK/EM, 2009)*

Hybrids between *Arachis hypogaea* and *A. kretschmeri*, a wild species from section *Procumbentes* and incompatible with cultivated species, were obtained. Hybrids were backcrossed to *A. hypogaea* and BC<sub>3</sub> hybrids were obtained. It was not possible to obtain selfed seeds from BC<sub>2</sub> plants. When BC<sub>3</sub> plants were selfed BC<sub>3</sub>F<sub>2</sub> seeds were obtained. Pod morphology of BC<sub>3</sub>F<sub>2</sub> resembled *A. hypogaea* with many double seeded pods. Molecular analysis has confirmed the hybridity of the progeny. Similarly, BC<sub>3</sub> plants were obtained as a result of crossing F<sub>1</sub> hybrid between *A. hypogaea* and *A. chiquitana* with *A. hypogaea*. It was possible to self plants in BC<sub>3</sub>F<sub>1</sub> generation to obtain BC<sub>3</sub>F<sub>2</sub>. Many of the BC<sub>3</sub>F<sub>2</sub> pods were single seeded, as seen in *A. chiquitana*, but with bigger pod size than in *A. chiquitana*.

N Mallikarjuna, DA Hoisington and HD Upadhyaya

*Milestone C.9.1.5: Tetraploid molecular map available for use in breeding program (NM/RV/HDU/DH/FW/PLK/CLLG, 2010)*

No report for 2007

### **Activity C.9.2: Broaden the genetic base of pigeonpea using *Cajanus platycarpus*, a tertiary gene pool species of *Cajanus***

*Milestones C.9.2.1: Generate fertile hybrids between Cajanus platycarpus and C. cajan (NM/DH/HDU, 2007)*

Hybrids between *Cajanus platycarpus* x *C. cajan* was generated using embryo rescue techniques in the F<sub>1</sub> and BC<sub>1</sub>F<sub>1</sub> generations. The hybrids were self-sterile until the BC<sub>3</sub> generation. Although it was possible to obtain backcross individuals, it was not possible to obtain seeds from self pollination until the BC<sub>3</sub> generation. It was possible to obtain seed by selfing the plants in BC<sub>4</sub>F<sub>1</sub> and obtain seeds of BC<sub>4</sub>F<sub>2</sub>. Screening BC<sub>4</sub>F<sub>2</sub> lines for various morphological traits showed some differences in plant growth habit, reaction to *Helicoverpa armigera*, and resistance to phytophthora blight.

N Mallikarjuna and DA Hoisington

*Milestone C.9.2.2: Generate variation for desirable characters using Cajanus platycarpus (NM/HDU/RKV/DH/KBS, 2009)*

Screening BC<sub>4</sub>F<sub>2</sub> lines for various morphological traits showed some differences in plant growth habit. BC<sub>4</sub>F<sub>2</sub>-A-21 line had dwarf growth habit in comparison to the spreading and semi-spreading growth habit in the remaining 25 lines. Significant differences between the lines for pod length and plant height were also observed. One line BC<sub>4</sub>F<sub>2</sub>-A-10-7 showed less than 0.1% infection to phytophthora blight disease when screened under artificial epiphytotic conditions. Differences were also observed for *Helicoverpa armigera* damage (15-45%).

N Mallikarjuna, HC Sharma, HD Upadhyaya and JS Sandhu (Ludhiana)

### **Output target C.10: Data management infrastructure development (2010)**

#### **LIMS development and dissemination:**

The Applied Genomics Laboratory (AGL)-LIMS is an application meant for information capture in high-throughput genotyping studies. The software has been available since 2004, first as an internet enabled application built on Microsoft technologies and later migrating to open standards and open source web based software (2006). The application, distributed under the GNU GPL (General Public License) is useful for the

capture, storage and retrieval of genotyping information generated during the course of crop diversity or mapping studies with functions spanning sample tracking, quality assurance, instrument interfacing, scheduling and reporting. The application is easy to deploy, maintain, upgrade and integrate. This has allowed for its multi-site deployment as well as data-center based implementations. Over the years, the application has improved to ensure easy navigation for the user while including a rich set of validations reducing the time needed to test the system when newly deployed. Functionality has also been increased and the open architecture has allowed for different implementations at different locations. The application has been used for genotyping using microsatellite markers or EST marker systems, and has been proven to support small to medium scale genotyping labs. The application is in use by the laboratory community at ICRISAT-Patancheru (an average of 40 user sessions/day) and Nairobi office by students, laboratory technicians, scientists, visiting scientists and laboratory manager. With the implementation of a module for instrument time scheduling at ICRISAT-Patancheru, the LIMS is set to handle information from every genotyping experiment the laboratory undertakes, allowing for better resource allocation in the laboratory and centralization of data generated.

The LIMS software requires a degree of configuration or customisation to meet the requirements of those adapting the application. While the sequence of the workflow is broadly fixed, modifications are possible at every individual step. This has indeed been the case for those adopting the system such as the seed company Mahyco; who have added further logical branches to the sequence of events in the genotyping workflow to suit their requirements when using the application in the genotyping of vegetables. While the programming language is not proprietary it still requires programming support in Java. For centers that were interested in adopting the application (IITA), but could not find programmers to do this, support was provided out of ICRISAT, while at IRRI, a software developer is available to take care of the customization. Since the application was made available in the public domain (July 2006), there have been 1233 downloads of the software by users outside ICRISAT. Of these, approximately 20% account for downloads from organizations based in the US and about 15% from Indian academic institutions, besides 5% each from Brazil and the UK. Where external users evinced interest in installing and assess the software for their needs at their location, the development team participated by providing help, out of academic interest. This has to a large extent helped in evaluating the system for performance under different technical specifications besides evaluating functionality. The software is now slowly inching towards collaborative development where those committed to adopting this software also commit to contribute to its improvement. The software is posted on cropforge (<http://cropforge.org/projects/icrisatlms/>), a site for the collaborative development of crop science related software applications. The LIMS is currently into corrective and perfective maintenance; meaning maintenance efforts are towards debugging existing functionality and adding new ones to the system.

#### **Activity C.10.1: Data capture instruments expanded and functionality increased.**

*Milestone C.10.1.1: Beta testing of the Laboratory information management system and improvement (JB/SS/RKV/DK and others, 2007).*

The Integrated ICRISAT Crop Resources Information System (ICRIS) has been developed as a three-tier application. The PostgreSQL database consists of 28 tables to store genotype and phenotype data from ICRISAT mandate crops. The middle tier consists of Java code that carries out the business logic (querying data from or persisting data into the database). The third tier comprises user interfaces written in JSP (Java Server Pages) through which the user interacts with the database. ICRISAT Patancheru users can access the database at <http://10.3.1.159/ICRIS>. Genotype and phenotype information is stored as datasets, which can then be browsed/retrieved by users through the user interfaces. The suite of query pages available allows retrieval of entire datasets for a chosen crop or all accessions in a dataset with the choice of generating composite datasets by combining data from two or more datasets. Allelic information may be retrieved as raw or called values for the chosen accessions across selected markers. The user is being provided with the means to run an allele-calling program on composite datasets. Quality indices for genotype data and annotation for phenotype data are also being made available to the user through the web pages. Data output format choices being provided to the user include requisite formats for common analysis programs. Templates that contributors of data must use to upload data into ICRIS are available through the web pages; these are modified versions of the Challenge Program genotype and phenotype data templates. Templates for submission of germplasm and marker data have been developed through user contributions. The database currently stores a small number of genotype datasets from chickpea and sorghum, phenotype datasets from pearl millet, groundnut and chickpea (generated during years 2005-2006). Efforts are also in progress to make ICRIS data available globally through web services; this is being done through registering ICRIS as a service provider in the Canadian BioMoby registry (<http://mobycentral.icapture.ubc.ca/cgi-bin>).

**Activity C.10.2: Integrated database development with web interfaces and interoperability requirements.**

*Milestone C.10.2.1: Development of database and middleware with GUI (JB/DH/ and others, 2007)*

The Integrated ICRISAT Crop Resources Information System (ICRIS) is a three-tier application, with a PostgreSQL database back-end to store genotype and phenotype data from ICRISAT mandate crops. The middle tier consists of a code that carries out the business logic (querying or persisting data from or into the database) while the view layer consists of Java Server Pages through which the user interacts with the database. ICRISAT Patancheru users can access the database at <http://10.3.1.159/ICRIS>. Genotype and phenotype information is stored as datasets, which can then be browsed/retrieved by users through the query pages. The suite of query pages allow retrieval of accessions in a dataset, choose accessions within or between datasets, retrieve raw or binned allele data for the chosen accessions across selected markers and output the data in formats suitable for analysis. Quality indices for genotype data and annotation for phenotype data are also available to the user through the web pages. The database currently stores a small number of genotype datasets from chickpea and sorghum, phenotype datasets from pearl millet, groundnut and chickpea (generated during years 2005-2006).

B Jayashree and DA Hoisington

*Milestone C.10.2.2: Alpha and beta testing of database by users (CTH/SS/RKV/HDU/RB/VV/and others)*

No report for 2007

*Milestone C.10.2.3: Curation of data with involvement of data providers.*

No report for 2007

**Output target C.11: Development of data analysis tools**

**Activity C.11.1: iMAS a decision support system for marker aided breeding (SC/DH/JB, 2007).**

The iMAS system has been extensively refined based on user feedback received from the International iMAS Testing Workshop held in May 2007 at ICRISAT, Patancheru. Version 1.0 of the system was released at the Generation Challenge Program's Annual Research Meeting held in Benoni, South Africa in September 2007. The system is available on CD or for download from ICRISAT Internet web site. The Version 1.0 package consists of six modules. The Data Validation Module checks whether the data are in a format as required by iMAS. The Phenotyping Module generates experimental design and undertakes biometric analyses. The Linkage Map Building Module builds linkage maps. The QTL Analysis Module undertakes QTL analyses. The Genome Display Module pictorially visualizes the genomic content to help select genetic material of desired genomic constitution. The MABC Sample Size Module determines sample size for backcross introgression. A major achievement of the project has been to provide Windows interface to all DOS-based programs, making it easier for a user to correctly, comfortably and confidently use these programs. The system, before release, was extensively tested on a wide range of different real datasets. A detailed User Manual was prepared and is part of Version 1.0 package.

S Chandra, DA Hoisington and B Jayashree

**Activity C.11.2: High performance computing toolbox. (JB/RKV/DH/SC and others)**

A number of software pipelines and standalone tools are being made available on the high performance-computing cluster for comparative genomics and population genetics analysis. There is demand for tools and pipelines relevant to comparative genomics and population genetics from users, and for optimal use of the HPC we identify popular software that can lend to parallel implementation. The use of the HPC is maximized through providing interfaces to implemented software so that users need not know how a cluster works to be able to use it. The comparative genomics toolbox includes a pipeline of open source software that can be used to mine large EST datasets for SNPs and identify restriction sites for assaying the SNPs so that cost-effective CAPS assays can be developed for SNP genotyping in genetics and breeding applications. The pipeline can be accessed through user-friendly web interfaces at <http://hpc.icrisat.cgiar.org/PBSWeb/> and has also been made available to external academic users. Besides, sequence analysis software like CLUSTALW, Muscle and phylogenetic

software (Phylip) are also available. The population genetics toolkit includes the program 'Structure' implemented within a parallel framework. A web-based user-oriented GUI has been implemented in the programming language PHP, through which the user can specify input parameters for the programme. The number of processors to be used can be specified in the background command. A web-based visualization tool "Visualstruct", written in PHP, allows for the graphical display of population clusters output from Structure. Besides, format conversion tools for a variety of popular analysis software is also available.

B Jayashree, RK Varshney, DA Hoisington, AG Sylvester,  
S Chandra, MS Hanspal and VT Jagdesh

### **Activity C.11.3: Comparative genomics tools to aid marker development. (JB/SS/CTH/RKV and others)**

#### ***Milestone C. 11.3.1: Development of appropriate software pipelines for mining of markers from public data (2008, Annual)***

Developed a software tool (CISprimerTool) for the identification of conserved intron scanning regions using EST alignments to a completely sequenced model crop genome. These markers are useful in exploring poorly characterized genomes for DNA polymorphisms resulting from the sequence variation of the introns. The tool automates the steps in identifying conserved intron-spanning exons, designing primers and verifying them electronically. The software can be accessed through user interfaces, and has been made available for download.

B Jayashree, VT Jagadesh and DA Hoisington.

### **Output D: RILs of staple crops and small millets developed/assembled and DNA extracts conserved and distributed**

#### **Summary**

RILs of chickpea (fusarium wilt resistance and root trait), pigeonpea (wilt resistance) and sorghum (resistance to stem borer and shoot fly) were assembled. Wide range of phenotypic diversity was observed in an M2 population in pearl millet.

Contrasting genotypes for salinity tolerance in chickpea, groundnut and pigeonpea have been identified to generate RILs.

Chickpea mini-core collection (211 accessions) and reference set (300 accessions) total genomic DNA was extracted for further genotyping studies.

Eight diverse chickpea and sorghum genotypes were selected from the chickpea and sorghum reference collections, respectively, and sequenced at CAP2 gene (homolog of DREB2A). The sequence analysis revealed a single SNP in the promoter region in chickpea and no SNP in CAP2 gene. In sorghum amplicons of about 800 bp were obtained and the sequence analysis revealed presence of one SNP in the sequence.

A large number of SSR markers are being developed and characterized in chickpea, pigeonpea, groundnut and pearl millet through various approaches. Screening of these new polymorphic markers in the mapping populations of these crops is in progress to construct the genetic map and for trait association mapping.

### **Output target D.1: RILs of staple crops assembled (2009)**

#### **Activity D.1.1: Assemble RILs of staple crops**

##### ***Milestone D.1.1.1: RILs of chickpea (root traits, resistance to Helicoverpa, fusarium wilt, BGM, and salinity tolerance) assembled (PMG/HDU/CLL, 2006)***

The interspecific RIL population, *Cicer arietinum* (ICC 4958) x *C. reticulatum* (PI 489777) (root traits) from Washington State University, Pullman, USA was multiplied during 2006/07 crop season in the field. Some RILs were too late and did not produce any seed. These are again being multiplied in the greenhouse from the remaining seed. Two intraspecific RIL populations, JG 62 x ICC 4958 (fusarium wilt resistance and root traits) and Vijay x ICC 4958 (root traits) obtained from National Chemical Laboratory, Pune, India are further being multiplied, as some lines died due to wilt during 2006/07 crop season.

PM Gaur, HD Upadhyaya and CLL Gowda

*Milestone D.1.1.2: RILs of groundnut (WUE-4, rust-2, and LLS-2) assembled (SNN/HDU, 2006)*

Completed and reported in 2006

*Milestone D.1.1.3: RILs of pigeonpea (one population of wilt resistance) assembled (KBS/HDU, 2007)*

From a cross involving ICPL 87119-1 (resistant) and ICP 2376-3 (susceptible) parents, RIL population, segregating for wilt is being generated. Selfed single plants of resistant and susceptible parents were planted in the wilt sick nursery and disease free plot. The seeds of each plant were divided into two lots, one planted in disease free plot and the other in the wilt sick plot. To carry forward the population by a modified single seed descent (SSD) method, the plant which died in wilt nursery, was replaced with the corresponding plant in the wilt free plot. A total of 267 plants in F<sub>4</sub> generation were harvested from the glasshouse for generation advancement.

KB Saxena and HD Upadhyaya

*Milestone D.1.1.4: RILs of pearl millet (3 populations) assembled (CTH/HDU, 2008)*

No report for 2007

*Milestone D.1.1.5: RILs of sorghum (grain mold-2, stem borer-3, and shoot fly-2) assembled (BVSR/HCS, 2008)*

For stem borer resistance, three populations [(ICSV 745 × PB 15520)-1, and its reciprocal, and (ICSV 745 × PB 15881-3)-3] involving 935 F<sub>3:8</sub> progenies (272 to 363 per cross) were advanced to F<sub>3:10</sub> during 2004-05 post-rainy season. Parents involved are stem borer resistant lines PB 15520, and PB 15881-3, and stem borer susceptible (but sorghum midge resistant) agronomically elite line ICSV 745.

For sorghum shoot fly resistance mapping, 252 F<sub>3:10</sub> progenies derived from the cross BTx623 (shoot fly susceptible but agronomically elite) × IS 18551 (shoot fly resistant but agronomically less elite) were advanced to produce F<sub>3:11S</sub> bulks and 529 F<sub>3:9</sub> progenies of reciprocal crosses between IS 18551 and 296B were advanced to F<sub>3:10</sub> to facilitate further studies on phenotyping and genotyping in 2008 post-rainy season.

BVS Reddy, A Ashok Kumar and HC Sharma

*Milestone D.1.1.6: TILLING population of pearl millet developed (RKV/CTH/DH, 2009)*

As reported in 2006, a set of 2581 M<sub>1</sub> lines were produced by using 5 mM (1169), 9 mM (737) and 10 mM (675) EMS treatment on the inbred line “P1449-2-P1”. With an objective to have one M<sub>2</sub> line from each M<sub>1</sub> line, approximately 20 seeds from 2581 M<sub>1</sub> lines each, were sown after considering all possible losses such as embryonic lethality and sterility. DNA was isolated from one seedling per each M<sub>2</sub> line out of the 20 seeds sown. A regular and systematic phenotypic survey was conducted on M<sub>2</sub> population and a wide range of phenotypic plasticity was observed (Figures 9 and 10). The M<sub>2</sub> lines, from which DNA was isolated were selfed and harvested (Figure 11). Seeds of these M<sub>2</sub> lines have been stored in pearl millet breeding unit (Tom Hash). DNA from all these M<sub>2</sub> lines was normalized to a concentration of 5 ng/ul.



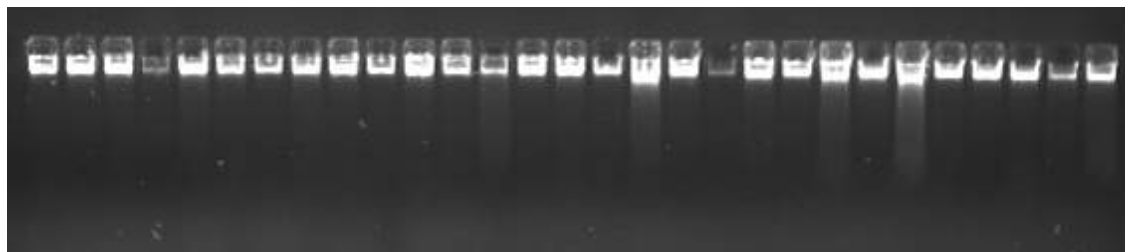
**Figure 9. Different form of observed mutants at later stage of plant development, a) early flowering, b) partial grain filling, c) sterile panicle d) nil to full grain filling, e) branched, f) forked panicle, g) deformed panicle h) early senescence**



**Figure 10. Variation in panicle size, thickness and grain fillings**

In order to enhance the set of existing mutant population, another lot of 10,000 seeds of the inbred line “P1449-2-P1” were treated with 7.5 mM EMS concentration. The mutagenized seeds were sown in the field. This treatment showed about 40% survival in the field. At present, the new set of M<sub>1</sub> plants is being harvested.

In parallel, literature search has been initiated to identify drought related candidate genes that can be used for TILLING in pearl millet.



**Figure 11. Genomic DNA on 0.8% agarose gel isolated from of M<sub>2</sub> lines.**

RK Varshney, T Mahender, CT Hash and DA Hoisington

#### **Activity D.1.2. Develop suitable contrasting parental lines for salinity tolerance in staple crops**

*Milestone D.1.2.1: Suitable contrasting parental lines for salinity tolerance in chickpea for the development of RILs provided (VV/RKV/HDU/PMG, 2007)*

Based on seed yield under salt stress conditions, 108 genotypes have been identified for salinity tolerance. Two crosses have been made between lines that contrast for salinity tolerance, but have similar phenology. This was done because of relationship between the time to flowering and salinity tolerance. This was confirmed by the phenotyping of a mapping population between ICCV2 (salinity susceptible) and JG62 (salinity tolerant) that revealed a clear segregation for time to flowering, with a strong interaction with the level of salt tolerance. The two crosses that are under development have parents with similar phenology: ICC 6263 (sensitive – days to flower = 70) x ICC 1431 (tolerant – days to flower = 69); and ICCV 2 (sensitive – days to flower = 39) x JG 11 (tolerant – days to flower = 40).

V Vadez, RK Varshney, HD Upadhyaya and PM Gaur

*Milestone D.1.2.2: Suitable contrasting parental lines for salinity tolerance in groundnut for the development of RILs provided (VV/SNN/AR/RKV/HDU, 2008)*

Crosses between three salinity sensitive advance breeding lines (ICGV 00309, ICG 2777 and ICG 4343) and three salinity tolerant parents (ICGV 86155, ICGV 87921 and ICG 6892) were made during the 2007 rainy season. F<sub>1</sub> seed has been harvested. Fresh crosses also will be made during the 2007/08 post-rainy season to get more number of F<sub>1</sub>s. Initially, studies would be conducted to identify the best parental combination, and the combination identified would be advanced to make RIL population.

A Rupakula and V Vadez

#### **Activity D.1.3: Assemble and make available for distribution the existent RILs of staple crops and small millets that are in the public domain in seed and DNA form**

*Milestone D.1.3.1: Seed multiplied for RIL populations for different crops (HDU/DH/CLLG/CTH/RKV/SS/RB/SNN/AR/PMG/KPS/KNR/BVSR, and others, 2009)*

No report for 2007

*Milestone D.1.3.2: DNA of different RIL populations isolated (HDU/DH/CLLG/CTH/RKV/SS/RB/SNN/AR/PMG/KPS/KNR/BVSR, and others, 2010)*

No report for 2007

*Milestone D.1.3.3: Marker and phenotype databases for the available RIL mapping populations curated (HDU/JB/DH/CTH/CLLG/RKV/SS/RB/SNN/AR/PMG/KPS/KNR/ BVSR, and others, 2010)*

No report for 2007

## **Output target D.2: DNA extracts of sub sets of germplasm conserved for utilization (2011)**

### **Activity D.2.1: Conserve DNA extracts of sub sets of germplasm for utilization**

*Milestone D.2.1.1: DNA extracts of mini-core and reference sets of chickpea conserved (HDU/RKV/DH/CLLG, 2008)*

Chickpea mini-core collection (211 accessions) and reference set (300 accessions) were planted in field. The genomic DNA was extracted from 20 days old young leaf tissue by using modified 3% CTAB method (Mace et al. 2003) in a 96-well format. DNA was further purified by RNase digestion followed by extraction using phenol/chloroform/iso-amyl alcohol and ethanol precipitation. DNA concentration was checked on 0.8% agarose gel and normalized to 5ng/  $\mu$ l working concentration for further genotyping studies.

N Lalitha, HD Upadhyaya, RK Varshney  
and DA Hoisington

*Milestone D.2.1.2: DNA extracts of mini-core and reference sets of groundnut and sorghum conserved (HDU/RKV/CTH/DH/CLLG, 2009)*

No report for 2007

*Milestone D.2.1.3: DNA extracts of mini-core set of pigeonpea conserved (HDU/RKV/CTH/DH/CLLG/KBS, 2010)*

No report for 2007

*Milestone D.2.1.4: DNA extracts of mini-core of finger millet and reference sets of pigeonpea, pearl millet and finger millet conserved (HDU/RKV/CTH/DH/CLLG/KBS, 2011)*

No report for 2007

*Milestone D.2.1.5: Requested DNA samples of specific accessions distributed for utilization (HDU/RPT/RKV/DH/NBPGR, Annual)*

No report for 2007

## **Output target D.3: Allele specific sequence diversity in the reference sets staple crops studied (2011)**

### **Activity D.3.1: Study allele specific sequence diversity in the reference sets of staple crops**

*Milestone D.3.1.1: Allele specific sequence diversity in the reference set of chickpea studied (RKV/HDU/DH, 2010)*

In order to obtain the possible DREB2A ortho/homolog sequences in seven targeted species (chickpea, common bean, barley, sorghum, rice, potato and cassava) under the framework of GCP sponsored “Allelic Diversity on Orthologous Candidate Genes” project, initial efforts were made using the consensus primer approach. Although the degenerate primer pairs yielded an amplicon with few primer combinations, these fragments, because of weak quality and smallness, in size, could not be sequenced. Similarly, even the use of heterologous primers could not provide any scorable and suitable product for sequencing. Therefore, the strategy was modified in order to retrieve corresponding sequences in the seven species. This consists of the reconciliation of species tree with gene tree, design of degenerate primers for each clade of the tree and primer optimization. By using this methodology and species specific primers, putative DREB2A orthologs have been identified in rice, barley, sorghum, chickpea and common bean. Subsequently a set of eight diverse genotypes of the reference collection was sequenced at these candidate orthologous sequences.

In case of chickpea, 8 diverse genotypes (Annigeri, ICCV 2, ICC 4958, ICC 283, ICC 8261, IC 10029, ICC 1882 and ICC 4411) selected from the reference collection were sequenced at CAP2 gene (homolog of DREB2A) and its promoter. As a result, amplicons of about 1000 bp for CAP 2 gene and 640 bp for promoter



were obtained. Sequence analysis in these genotypes however revealed only a single SNP in the promoter sequence while no SNP was observed in the CAP2 gene.

Like DREB2A at ICRISAT, other collaborative partners have identified the putative homologs of ERECTA in chickpea. At present, it is planned to sequence the reference collection of chickpea at ERECTA and promoter region of CAP 2 gene. Isolation of other candidate gene (eg, Sucrose Synthetase, Abscisic acid Stress Responsive genes) in chickpea is in progress.

RK Varshney, S Nayak, B Jayashree,  
HD Upadhyaya and DA Hoisington

*Milestone D.3.1.2: Allele specific sequence diversity in the reference set of sorghum studied (CTH/RKV/HDU/DH, 2011)*

By using the above mentioned approach (D.3.1.1), DREB2A homolog was obtained in sorghum. Subsequently, a set of 8 diverse sorghum genotypes (BTX 623, B35, E36-1, R16, IS 9830, IS 27761, IS 29233, IS 18933) representing the diversity of the reference collection was used for sequencing DREB2A homolog. As a result, amplicons of about 800 bp were obtained in 8 genotypes and sequenced. The sequence analysis revealed the presence of one SNP in the sequence.

RK Varshney, S Nayak, B Jayashree,  
CT Hash and DA Hoisington

#### **Output target D.4: Development of genomic resources for SAT crops (2011)**

##### **Activity D.4.1: Development of molecular markers**

*Milestone D.4.1.1: Novel set of microsatellite markers developed and characterized for chickpea, pigeonpea and groundnut (RKV/DAH)*

In total, 311 SSR primer pairs (ICCM series) were designed based on SSRs isolated from the SSR-enriched library in chickpea. The primer aliquots for these SSR primers have been distributed, before publishing the primer sequences, to several partners including Washington State University, USA (Fred Muehlbauer), Murdoch University, Australia (Richard Oliver), National Chemical Laboratory, Pune (Vidya Gupta), GenXPro/ University of Frankfurt, Germany (Peter Winter), and National Research Centre on Plant Biotechnology, India (Ramamurthy Srinivasan), Sardar Vallabh Bhai Patel University of Agriculture & Technology, Modipuram (Rajendra Kumar). A report on generation of these SSR markers has been published in e-SAT Journal of Agricultural Research (Varshney et al. 2007).

Apart from the above mentioned SSR markers, another effort has been made to isolate the SSRs from the Bacterial Artificial Chromosome (BAC) sequences (BES) in collaboration with University of California, Davis, USA. A total of 46,270 chickpea BAC-end sequences, representing 33.2 Mb genome size, were obtained from UC-Davis and surveyed for the presence of microsatellite using *MicroSATellite (MISA)*. In total, 6845 SSRs were isolated from 33,217 kb BES at a frequency of 1 SSR per 4.85 kb. In this set, di-nucleotide motifs were the most abundant (37% of total SSRs), while tri-nucleotide motifs were second most abundant (~10% of total SSRs). Most di- and tri-nucleotide sequences were AT-rich (ie, TA and TAA), comprising ~2/3 of SSRs in chickpea. With the goal of enhancing the SSR repertoire in chickpea, primer pairs were designed for 1344 chickpea SSRs (CaM series).

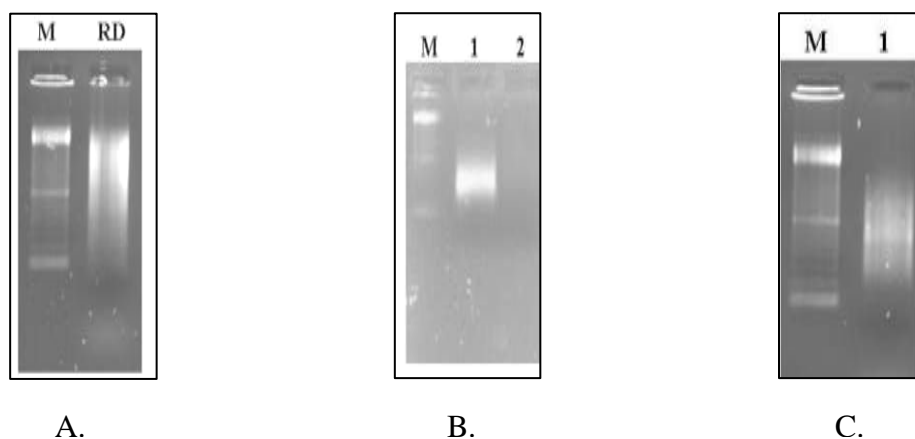
Both, the ICCM and CaM series SSR markers are currently being screened on parental genotypes of inter- and intra- specific mapping populations of chickpea.

RK Varshney, S Nayak, N Varghese,  
D Cook and DA Hoisington

To develop the SSR-enriched libraries in pigeonpea, the pigeonpea variety "Asha" was selected and genomic DNA was digested using *RsaI* and *XmnI*. The restriction digestion was confirmed by a uniform smear around 500 bp on a 1.2% agarose gel (Figure 12A). In order to ligate double stranded (ds) Super SNX linkers to digested DNA, ds linkers were prepared by annealing equimolar concentrations of single stranded Super SNX24 and Super SNX24+4P primers to each other. Ligation of ds linkers to digested DNA fragments for enrichment of DNA fragments was performed at the molar ratio of 1:10 (DNA fragments: ds linkers). Ligation was confirmed by PCR amplification with linker specific primer SuperSNX24. A thick smear was formed between



300 bp and 1000 bp (Figure 12B). In this way, genomic DNA libraries were enriched for five SSRs (CT, TG, AG, AAG and TCG). Hybridizations of the ligation mixture to the five different biotinylated repeat oligonucleotides were achieved by incubations at their respective hybridization temperatures. The reaction was confirmed by PCR using linker specific Super SNX24 primer. A smear was formed around 500 bp indicating the successful hybridization of repeat containing DNA fragments (Figure 12C). Subsequently, the ligation and transformation were accomplished by using the TA cloning vector (Invitrogen, USA) and competent TOP10 cells. After allowing the cells to recover at 37°C for an hour, they were plated on LB<sup>+amp</sup> agar with IPTG and X-gal, and incubated at 37°C overnight. All white colonies were picked up. Subsequently, the dot-blot membranes were prepared for about 4,000 colonies and are being used to hybridize with the SSR probes that were used for enrichment.



**Figure 12. A, B and C. Steps involved in generating SSR enriched libraries (A) Restriction digestion of genomic DNA, M = 100 bp DNA ladder, RD= Digested genomic DNA; (B) Linker ligation, M = 100 bp DNA ladder, 1 = Linker ligated DNA, 2 = Negative control; (C) Enriched SSR genomic DNA fragments, M = 100 bp DNA ladder, 1 = Enriched DNA.**

RK Varshney, C Prathima and DA Hoisington

*Milestone D.4.1.2: Novel set of microsatellite markers developed and characterized for pearl millet (RKV/CTH/SS/DAH)*

A total of 960 SSR-enriched clones isolated from the SSR enriched library in collaboration with Centre for Cellular and Molecular Biology (CCMB), Hyderabad (Dr Ramesh Aggarwal) have been sequenced. In total, 1010 sequences were obtained and surveyed for the presence of SSRs. The SSR search with the help of *MicroSATellite* tool identified 1507 SSRs in 1010 sequences with the frequency of 1 SSR per 5.1 kb. However, a total of 454 primer pairs could be designed using the PRIMER3 programme and synthesized. So far, 32 primer pairs have been screened on 24 elite inbred lines including the parental genotypes of eleven mapping populations. As a result, 8 markers showed polymorphisms in genotypes examined. These markers detected allele in the range of 2-7 with the PIC value from 0.33 to 0.79. Efforts are underway to screen the remaining set of markers on these genotypes.

RK Varshney, T Mahender, R Aggarwal and DA Hoisington

In case of groundnut, an *in silico* approach was used to identify SSRs from the available nucleotide sequences from species within the aeschynomenoid/dalbergoid and genistoid clades of the Leguminoae family. The SSR search and primer designing provided the primers for 109 unique SSRs. Screening of representative accessions from 6 genera within the aeschynomenoid/dalbergoid and genistoid clades showed 60% of the total cross-genera transferability. However, only with 51 of the 109 SSRs showed amplification in *Arachis hypogaea*. These 51 SSRs were further tested against 27 diverse *Arachis* accessions and 18 revealed polymorphism. Thus a novel set of 51 SSR markers were developed and validated in cultivated groundnut species.

E Mace, JH Crouch and RK Varshney

**Activity D.4.2: Development of molecular genetic maps**

*Milestone D.4.2.1: Molecular genetic maps and consensus maps based on SSRs, DArTs and EST-based markers developed for chickpea, pigeonpea and groundnut (RKV/DAH/PMG/KBS/SNN/HDU)*

For developing the genetic maps in chickpea, currently three recombinant inbred line (RIL) mapping populations ie, one interspecific (*C. arietinum* ICC 4958 × *C. reticulatum* PI 489777) and two intraspecific (ICC 4958 × ICC 1882; ICC 283 × ICC 8261) are being used. At present in chickpea, we have 2168 microsatellite markers consisting of both existing and newly developed microsattellites at ICRISAT. Screening of these markers on the parental genotypes of these mapping populations is in progress. The interspecific cross ICC 4958 × PI 489777 showed high level of polymorphism, ie, 355 novel SSR markers are polymorphic among 1416 total primers amplified (25%); 124 polymorphic markers (21%) among 581 amplified markers were identified in intraspecific cross ICC 4958 × ICC 1882 and 148 markers (25%) are polymorphic among 581 scorable markers in ICC 283 × ICC 8261 (Table 13). Screening of polymorphism for other markers is in progress and simultaneously the polymorphic markers are being screened on recombinant inbred lines of the respective mapping populations to prepare linkage maps and trait mapping at ICRISAT. The current status of the microsatellite markers is given in the following table.

**Table 13. Polymorphism survey in parental genotypes of mapping populations.**

| Markers              | Total | ICC 4258 x PI 489777 |          |             | ICC 4958 x ICC 1882 |          |             | ICC 283x ICC 8261 |          |             |
|----------------------|-------|----------------------|----------|-------------|---------------------|----------|-------------|-------------------|----------|-------------|
|                      |       | Screened             | Scorable | Polymorphic | Screened            | Scorable | Polymorphic | Screened          | Scorable | Polymorphic |
| Texas A&M University | 233   | -                    | -        | -           | 233                 | 153      | 36          | 233               | 153      | 42          |
| NIPOR                | 280   | -                    | -        | -           | 280                 | 203      | 62          | 280               | 203      | 82          |
| ICRISAT(ICGM)        | 311   | 311                  | 225      | 74          | 311                 | 225      | 26          | 311               | 225      | 24          |
| ICRISAT & UCD(CaM)   | 1344  | 1344                 | 1191     | 281         | -                   | -        | -           | -                 | -        | -           |
| Total                | 2168  | 1655                 | 1416     | 355         | 824                 | 581      | 124         | 824               | 581      | 142         |

RK Varshney, N Varghese, S Nayak, PM Gaur, J Kashiwagi and DA Hoisington

In case of pigeonpea, the progeny lines of the interspecific F2 population (*Cajanus cajan* ICP 28 x *C. scrabaeoides* ICPW 94) has been screened with the SSR markers developed at ICRISAT and DArT markers. It has been planned to genotype the mapping population with polymorphic SSR and DArT markers.

RK Varshney, HD Upadhyaya and DA Hoisington

The RIL mapping population of groundnut (ICGV86031 x TAG24) is being used for developing the genetic map for cultivated groundnut. All the existing SSR markers for groundnut as well as unpublished markers from some research groups eg, David Bertoli (Catholic University/EMBRAPA, Brazil) and Steve Knapp (University of Georgia, USA) have been screened on the parental genotypes of the mapping population. As a result, >120 SSR markers have shown the polymorphism. These polymorphic markers have been used for genotyping of the mapping population and currently genotyping data are being used to calculate the genetic map.

RK Varshney, V Vadez, SN Nigam, A Rupakula and DA Hoisington

*Milestone D.4.2.2: Molecular genetic maps and consensus maps based on SSRs, DArTs and EST-based markers developed for pearl millet (RKV/CTH/SS/DAH)*

After screening a total of 627 markers (100 genomic SSRs, 60 EST-SSRs, 100 pearl millet SSCP-SNPs, 57 wheat SSCP-SNPs, 310 CISP-SNPs) on 24 genotypes including parental genotypes of 11 mapping populations (H 77/833-2 x PRLT 2/89-33; ICMB 841-P2 x 863-P3; Tift 23D2B1-P5 x WSIL-P8; PT 732B-P2 x P1449-2-P1; LGD 1-B-10 x ICMP 85410-P7; 81B-P6 x ICMP 451-P8; 81B-P6 x ICMP 451-P8; ICMP 451-P6 x H 77/833-2-P5 (OT); W 504-1-P1 x P310-17; IP 18293-P152 x Tift 238D1-P158; ICMB 89111-P6 x ICMB 90111-P6 and IPC 804 x 81B ) and two other inbred lines (Tift 383 and Tift 186), the 100 markers showed polymorphism in ICMB 841-P3 × ICMB 863-P2 cross. These polymorphic markers (27 gSSRs, 22 pearl millet SSCP-SNP, 51 CISPs) were used for genotyping the 150 F6 lines of the corresponding cross. Newly developed SSR markers (see Milestone D.4.1.2) will be used to identify the polymorphism and genotype the mapping population.

In order to enhance the density of the consensus map, common polymorphic markers between two populations (ICMB 841-P3 × ICMB 863-P2 and 81B-P6 × ICMP 451-P8) and unique polymorphic markers in 81B-P6 ×

ICMP 451-P8 population are being used for genotyping the 81B-P6 × ICMP 451-P8 population. Eventually, a comprehensive consensus genetic map based on the above mentioned two populations will be developed.

RK Varshney, T Mahender, CT Hash,  
S Senthilvel and DA Hoisington

**Output target D.5: Agriculturally beneficial microorganisms assembled for utilization (2010)**

**Activity D.5.1: Assemble and conserve agriculturally beneficial microorganisms for utilization and distribution**

*Milestone D.5.1.1: Agriculturally beneficial microorganisms from diverse environments accessed and characterized for 6 different traits – P- solubilization, antagonism to disease-causing fungi, pathogenicity to insect-pest, siderophore production (OPR, Annual)*

During 2007, 250 new microbial cultures were accessed from four different sources: a) DRR field at ICRISAT, Patancheru, b) compost prepared at ICRISAT based on an innovative method learnt from farmers and involving root rhizosphere of diverse crops during composting, c) sorghum rhizosphere, BW3 field, ICRISAT, Patancheru and d) post-rainy sorghum fields of the research station of National Research Center for Sorghum (NRCS) at Sholapur. Of the 250 cultures, 200 were bacteria and remaining actinomycetes. The bacterial cultures were characterized for four different traits and number of cultures accessed for each category is given in Table 14.

**Table 14: Number of bacterial cultures characterized for different traits.**

| S. No | Trait                                                                                 | Number of cultures |
|-------|---------------------------------------------------------------------------------------|--------------------|
| 1     | P- solubilization + at least one more beneficial trait                                | 32                 |
| 2     | Antagonism to disease causing fungi + at least one more beneficial trait              | 66                 |
| 3     | Siderophore production + at least one more beneficial trait                           | 151                |
| 4     | N <sub>2</sub> fixers ( <i>Azotobacter</i> like) + at least one more beneficial trait | 124                |

OP Rupela

*Milestone D.5.1.2: Existing collection of agriculturally beneficial microorganisms conserved for medium and long-term storage system and annually 20% germplasm attended (OPR, Annual)*

Two hundred and ninety-eight previously collected cultures were studied for six different characters: a) ability to withstand low (15°C) and high (50°C) temperatures, b) ability to withstand boiling, c) P-solubilization, d) siderophore production, e) antagonism to *Macrophomina phaseolina* (causes charcoal rot in sorghum), and f) endotoxin production as judged by staining method. Fifty-three of these were preserved at -80°C.

OP Rupela

*Milestone D.5.1.3: Requested agriculturally beneficial microorganisms distributed to bonafide users for utilization (OPR, Annual)*

Requests received were for rhizobia, (nodule forming bacteria), and for those microorganisms with ability to help manage insect-pests. Sixteen vials of rhizobial cultures and 228 units (one unit is sufficient to cover one acre area) of carrier based inoculants of different rhizobial strains were provided on request. Three vials and 102 units of carrier-based entomopathogens were also provided. The requests were from NARS scientists, partners of Bioproducts Research Consortium (BRC) and scientists at ICRISAT.

OP Rupela

**Project 3:  
Producing more and better food of the staple cereals and legumes of the west and  
central African (WCA) SAT (sorghum, pearl millet and groundnut) through  
genetic improvement**

**System Priority 2: Producing more and better food through genetic improvement**

Priority 2A Maintaining and enhancing yield and yield potentials of food staples

Priority 2A, Specific goal 1: Enhance capacity and efficiency of genetic improvement programs through approaches linking characterization and use

Priority 2A, Specific goal 2: Identification of pro-poor traits

**Output 3.1 Heterotic relationships identified within sorghum and pearl millet germplasm adapted to WCA conditions and appropriate broad-based breeding populations and hybrid parents and knowledge made available to NARS and other partners in order to maximise genetic gain from selection**

Priority 2A Maintaining and enhancing yield and yield potentials of food staples and 2B: Tolerance to selected abiotic stresses

Priority 2A, Specific goal 1: Enhance capacity and efficiency of genetic improvement programs through approaches linking characterization and use

Priority 2A, Specific goal 2: Identification of pro-poor traits

Priority 2B: Tolerance to abiotic stresses

**Output 3.2 Improved methodologies developed for integrating breeding of groundnut, sorghum and pearl millet populations and varieties with crop management strategies to overcome key environmental and socio-economic constraints and making them available with new knowledge to partners**

Priority 2C: Enhancing nutritional quality and Safety:

Priority 2C, specific goal 1: Increase the content of micronutrients in the edible parts of crop plants through improved biotechnologies and breeding

Priority 2C, specific goal 2: Evaluation of bio-fortification strategies and introduction of the best means to enhance the diets of nutritionally disadvantaged populations in developing countries

Priority 2C, specific goal 3: To reduce the content of constitutive or microbial toxins in selected staples that affect quality, food safety and human health

**Output 3.3 Crop management, Aspergillus flavus resistant groundnut varieties and post-harvest technologies to reduce aflatoxin contamination in food and feed products, as well as micronutrient rich cereal varieties and processing techniques to improve bio-availability developed, tested and made available to partners with new knowledge in the SAT of WCA**

### **Output 3.1 Heterotic relationships identified within sorghum and pearl millet germplasm adapted to WCA conditions and appropriate broad-based breeding populations and hybrid parents and knowledge made available to NARS and other partners in order to maximise genetic gain from selection**

Heterotic grouping of germplasm and breeding materials is an important tool for managing breeding material for maximum genetic gain, not only for hybrid breeding, but also managing populations for variety development. The project team has made good progress at identifying and using heterotic groups, both in sorghum and pearl millet. A large set of germplasm for each of the crops has been characterized by using markers, and analyzed for observable patterns of diversity. Factorial crossing to test either hybrids (sorghum) or population crosses has been initiated. The experience working with guinea race sorghum hybrids over the past three years, also is leading to the identification of groups of materials that results in superior hybrids when crossed. We have largely broadened the scope for these evaluations, as breeders in at least five National programs have received seed of A-lines to be able to produce hybrids with locally well adapted varieties. For pearl millet five national programs have conducted one or more factorial and diallel set of population crosses for evaluation in one of the target zones for pearl millet improvement.

#### *MTP Output Target 2007 3.1.1*

#### *SSR genotyping of 250 pearl millet and 210 sorghum accessions assessed for heterotic grouping*

The germplasm finally selected for genotyping comprised of 254 pearl millet and 210 sorghum landraces or improved breeding materials mainly from West and Central Africa but some also from other regions of the world. The sorghum accessions characterized for molecular genetic diversity patterns were chosen to represent the pool of germplasm to produce hybrids with adaptation and grain quality required for West Africa. The accessions included landrace varieties from the Guinea-race Core Collection of Eastern/Southern African, Asian, and West African origin, collections of landrace varieties from Mali, Burkina Faso and Nigeria, and breeding lines, particularly maintainer and restorer lines, developed and/or used by hybrid breeding programs of IER-Mali, ICRISAT-Mali and INRAN-Niger. The sorghum accessions included a range of maturity and racial types that would be of interest for the contrasting Sahelian, Sudanian and Guinean zones of West Africa from Senegal to Nigeria.

Seed of the selected materials were sent from the regional breeding programs at ICRISAT-Niger (pearl millet) and Mali (sorghum) to the BecA laboratory (Kenya) for DNA extraction. DNA extraction was achieved for 211 pearl millet and 158 sorghum accessions. The extracted DNA was then genotyped at ICRISAT's high-throughput laboratory in India by a West African trainee. Useful data for the diversity analysis was finally obtained for 16 SSRs on 201 pearl millet accessions, and 33 SSR markers on 158 sorghum accessions. This marker data was used to analyze the similarity between individual pairs of accessions using the DARwin software package.

These preliminary analyses of the SSR marker data indicated clear differentiation of the materials according to geographic origin, germplasm type (pearl millet) or race. The graphical representations of the molecular genetic marker diversity of the 158 sorghum accessions provide initial glimpses at the patterns of genetic diversity (See Figures in Project 2). The apparent complete overlapping of early-, intermediate- and late-maturing materials is striking, and suggests that different maturity groups do not constitute genetically distinct pools and that maturity (photoperiod-temperature sensitivity of floral initiation) should not constitute a major barrier to accessing the major genetic variability in West-African adapted materials (Figure a). Examination of the diversity pattern within the Guinea race sorghum materials suggests that a) distinct pools within the Guinea race can be developed as separate heterotic groups, important for successful development of Guinea-race hybrids that retain the distinctive grain/glume characters needed for adaptation and economic utility; and b) that the Guinea-Caudatum inter-racial breeding materials form a separate group (Figure b).

This preliminary information is now being used to further select parental materials from genetically distinct groups for production of crosses and validation of heterotic groups. However, much more systematic and detailed examination of these diversity data is needed for definitive groupings and identification of potential heterotic groups that could be successfully implemented for hybrid sorghum breeding in West Africa.

In addition, two Kenyan M.Sc. students analyzed subsets of the selected accessions to study both inter- and intra-accession diversity patterns in a more detailed manner. The first student, Mary Onsarigo genotyped 30 pearl millet accessions with 21 SSR markers. Overall high levels of genetic diversity were found. The particularly high intra-population diversity and lower differentiation between the West African pearl millet

landraces were attributed to the out-crossing behavior of the crop; both pollen flow and seed exchange seem to contribute to the observed diversity patterns. Observed clusters of accessions based on SSR marker diversity are being used to tentatively define heterotic groups that will be validated through heterosis and combining ability studies. The second student, Mercy Kitavi, analyzed the diversity between and within 30 sorghum accessions using 22 SSR markers and is currently finalizing her thesis.

S Boureima, CT Hash, S Senthilvel, P Ramu, D Kiambi,  
M Onsarigo, M Kitavi, F Rattunde, E Weltzien,  
HK Parzies, D Hoisington and BIG Haussmann

*MTP Output target 2007 3.2.1*

*Partners from WCA trained in the use of participatory recurrent selection and hybrid breeding techniques (partly associated with the PGRA SWEF).*

A “West African Training Workshop on Hybrid Sorghum and Pearl Millet Breeding” was conducted at ICRISAT Mali during April 17-19 to strengthen regional capacity in hybrid breeding. A group of 39 Sorghum and Pearl Millet researchers from 6 West African countries (Senegal, Mali, Burkina Faso, Ghana, Niger, Nigeria), private seed sector representatives from Nigeria and the United States and an INTSORMIL and a University of Hohenheim collaborator participated in the training workshop. The objectives of the workshop were to strengthen technical skills through systematic review of principles and techniques for successful hybrid breeding, sharing experiences and practical methods for field activities, and identifying priority opportunities and requirements for hybrids in the region.

The formal presentations were on heterosis and heterotic groups, combining ability, breeding male- and female-parents, program design of commercial breeding programs, and information on key panicle, grain and flowering response traits required for adaptation. Participants also shared experiences in field observations, crossing techniques and parental seed multiplication. The group concluded the workshop with discussion of future activities and potential funding for their implementation. Regional collaboration was identified as a key requirement for success in this endeavor, and strong willingness to exchange germplasm and conduct joint testing was expressed.

The workshop proceedings are published.

A training program on participatory recurrent selection was held in Segou during 8-17 September 2006 with 23 participants including NARS pearl millet and sorghum breeders, development workers, farmers’ organization representatives, plant breeding students and research technicians. The course focused on three thematic areas:

(i) Priority setting and identifying specific objectives for a breeding program: The group discussed the different issues for which a plant breeding requires priorities, such as the target environment and production system, base germplasm to be used, selection criteria and roles and responsibilities of the different partners. The discussion of different methods for recurrent selection of pearl millet and sorghum took up a large part of the course, constantly examining options for farmer involvement in the decision making process. Each country group planned activities for their sites, and with the material available to them, involving the different partner organizations.

(ii) Communication tools specifically useful for participatory breeding projects and their orientation: The participants had a chance to put their communication skills into practice during a visit to some of the villages where IER scientists were working near the Cinzana research station.

(iii) The organizational and institutional options for planning and implementing a participatory recurrent selection program were another thematic area for intense discussions. We examined the organizational set-up of the IFAD funded investment projects for achieving farmer capacity building to enable them to achieve higher production, and improve their access to markets. Similarly the farmer organizations described their approaches to creating innovations and other benefits for their members. This session was particularly important for the planning of PROMISO project activities, as this project does not envisage creating new models of farmer researcher interactions, but rather builds on existing experiences, institutions, and investments into strengthening local organizations, and innovation processes.

An additional group of four breeders from WCA partner countries were trained together with scientists, extension workers and farmers from the Eritrean national pearl millet program, during a training course held in Eritrea, focusing on pearl millet.

E Weltzien, HFW Rattunde, CT Hash,  
BIG Haussmann and K vom Brocke

#### *MTP Output Target 2007 3.3.1*

##### *Integrated aflatoxin management practice knowledge distilled and disseminated to partners*

Groundnuts are prone to infestation by two closely related fungal species, *Aspergillus flavus* and *A. parasiticus*. Both fungal species produce a highly toxic group of mycotoxins known as aflatoxins. Health effects in humans and livestock due to consumption of aflatoxin-contaminated foods include impaired growth, liver and other cancers, immuno-suppression, and death. These toxins can contaminate an array of crops including maize, groundnuts, spices and tree nuts.

ICRISAT and partners in WCA have developed several technologies that can reduce risks of aflatoxin contamination in groundnuts. These include genetic resistance and integrated crop management practices, agronomic practices, biological control and biotechnological interventions.

Five resistant/tolerant cultivars were evaluated by 10 farmers in five villages of Kolokani district of Mali under their own management practices over a period of three years (2004-2006). A number of agronomic practices that minimize risk of pre-harvest infection by *Aspergillus flavus* were tested in two major groundnut growing areas in Mali (Kolokani and Kayes) (2003-2005). These technologies included the application of lime, farmyard manure (FYM), crop residues (CR) and their combinations using an aflatoxin resistant (55-437) and a susceptible (JL 24) cultivar.

Several appropriate harvesting and drying techniques, such as avoiding damage to pods, harvesting at maturity, proper drying of pods immediately after harvest were also tested in farmers' fields and demonstrated in Kolokani and Kayes (Mali); Samaru in Nigeria and Kaolack in Senegal. Aflatoxin contamination was monitored in market samples of groundnut products from Mali.

The key results of all the aflatoxin management work are as follows:

The tolerant varieties showed significantly lower levels of *A. flavus* infection and aflatoxin contamination compared to the susceptible control varieties. For example, ICG 6101 and ICG 7 recorded low aflatoxin content of <1.0 µg/kg compared to 1.02 µg/kg for the resistant variety 55-437 and 92.49 µg/kg for the susceptible variety Fleur 11. The results confirm the tolerance of these varieties to aflatoxin contamination. Thus they can play a significant role in the integrated management for reduction of aflatoxin in foods prepared from groundnuts.

Among the agronomic practices tested and demonstrated, the application of lime was the most effective; it reduced contamination by 73% and 85% at Kolokani and Kayes, respectively. A combination of farmyard manure and crop residues reduced aflatoxin contamination by 46-74% compared to the control treatment.

Best-bet harvesting and drying techniques such as avoiding damage to pods, harvesting at right maturity and proper drying of pods led to a significant reduction in aflatoxin contamination ranging from 69 to 88% in Kolokani and from 63 to 84% in Kayes, in Mali. Similar results were obtained in Nigeria.

On an average, 55.3% of the farmers who participated in the on-farm trials produced groundnut with less than 10 µg/kg aflatoxin compared to 7% of non-participants.

High levels of aflatoxin were recorded in samples (kernels and paste) collected in various markets in Mali. Out of 360 samples, only 14% had aflatoxin contents of less than 20 µg/kg. Aflatoxin contents of over 2000 µg/kg were also recorded.

The general conclusion from these results is that while it is possible to control aflatoxin contamination at the production and harvest levels, the causal agent (*Aspergillus flavus*) seems to represent a major problem at the transport and storage level. Thus proper handling is equally important. The on-farm results need to be scaled-up and out to larger geographical areas and include appropriate mechanisms and linkages to leverage changes in

policy and institutions to effectively address marketing constraints and health concerns for local consumers. However, this requires additional resources.

A syntheses report documenting the results, experiences and lessons learned was compiled, edited and is being prepared for printing. This will be distributed to partners.

A regional dissemination workshop was held in Bamako, Mali, from 2-3 July 2007 to present the results of the just concluded project on the “Development of Sustainable groundnut seed systems in West Africa”. Measures to minimize aflatoxin contamination were a major component of the project. A paper on on-farm management of aflatoxin contamination was presented and will appear in the proceedings of the workshop being prepared for printing. Forty six (46) participants including the key actors along the value chain (researchers, farmers, traders, processors and policy makers) attended the workshop. Other dissemination pathways have been through flyers, brochures in various languages (English, French, Bamabara and Hausa). These have been widely distributed in Mali, Niger, Nigeria and Senegal.

BR Ntare, F Waliyar AT Diallo, O Kodio and B Diarra

#### *MTP Output target 2007 3.3.2 Human mineral nutrition (Fe, Zn) and role of sorghum and pearl millet assessed in Mali*

Malnutrition is a serious problem in the semi arid tropics where sorghum and millet are the staple crops. The contribution of cereals to the overall diet in terms of energy is extremely important, but there is not much known about the importance of these crops for mineral nutrition and on the current practices with regard to grain processing, food preparation and eating practices. Therefore, the consumption of sorghum and millet and its contribution to mineral nutrition was assessed by a study compiling and synthesizing existing literature of Mali, Burkina Faso and Niger. The findings stress the importance of cereals to the overall diet in West Africa, providing 67-90% of the energy intake and 67% of the iron intake. The food consumption does not meet the nutritional needs, in particular for children under five. The main reasons for the inadequacy of the diet are the low bioavailability of minerals from cereals, low energy density of complementary food, non-availability of foods and food habits. The recommendations of the report include the further development and introduction of improved sorghum and millet varieties with a higher iron and zinc bioavailability, dietary diversification, and improved transformation of cereals in order to increase mineral absorption and energy density.

The report “Millet and Sorghum Consumption and Contribution to Human Nutrition in Mali, Niger and Burkina Faso – With Specific Focus on Micronutrients” is published in French and English and distributed amongst partners and continues to be available.

In order to complete the picture on the role of sorghum and millet in human nutrition, a study on individual level food intake took place in 12 households in the zones of Mandé, Dioila and Tenenkou. The study aimed to assess dietary intake and to complement current household food consumption data. The study estimates revealed that cereals provide more than 74% for the dietary iron and 84% of the dietary zinc. Cereals are consumed in the form of thick paste, couscous or porridges and accompanied by a low nutrient dense sauce. Therefore, the high cereal contribution to mineral intake is mainly due to the low diversity of the diets.

#### *Output Target 2008 3.1.1: Enhanced access and capacity development of NARS to new, characterised diversity of sorghum and millet germplasm in adapted backgrounds*

In pearl millet, a second-year farmer-participatory characterization of 119 WCA accessions selected from last year’s characterization trials was performed in cooperation with the NARS of Senegal, Mali, Burkina Faso, Niger and Nigeria. This year, materials were divided according to adaptation of the materials into three different agro-ecological zones. Fifteen extra early accessions were evaluated at five locations in the Northern Sahelian zone (1 location each in Senegal, Mali, Burkina Faso, Niger and Nigeria); 72 early- to medium-maturity entries were tested at 6 locations in the Southern Sahelian/Northern Soudanean zone (2 sites in Niger, one site each in Nigeria, Burkina Faso, Mali, and Senegal), and 32 late-maturing accessions at three locations in the Soudanean zone (one site each in Niger, Mali, and Senegal). The multi-location data gained with these and last year’s trials will provide insight into adaptation and yield stability of the tested materials for various agro-morphological and performance traits as well as farmer preferences.

All scientists contributing to this germplasm evaluation effort participated in training sessions focusing on heterotic grouping, combining ability analyses, and the use of specific software to conduct these analyses.

BIG Haussmann and NARS partners



A total of 80 well-adapted, diverse, sorghum landrace and bred varieties were collected and identified by National programs from Nigeria (26), Burkina Faso (8), Ghana (26), Mali (10), and ICRISAT-Mali (6). ICRISAT prepared 16 Regional Sorghum Germplasm Evaluation Nurseries and protocols with the germplasm provided. Nurseries containing early to intermediate maturity varieties were prepared for more northern locations, and intermediate to late maturity varieties for the longer growing-season sites further south. Nurseries were sent to Nigeria (Kaduna, Kano, Zamfara, Kebbi, Sokoto, Katsina and states), Burkina Faso (Fada N’Gourma, Saria), Ghana (Tamale), Niger (Bengou, Maradi and Aguié), and Mali (Cinzana, Sotuba, Samanko (two dates of sowing)). F. Rattunde visited 11 of these nurseries for making observations together with the respective National Program partners prior to harvest. Initial observations indicate that resistance/tolerance to specific insect pests is a key adaptation determinant as well as photoperiod sensitivity and crop duration. For example, serious midge damage, up to 100% on susceptible varieties, was observed at Saria, Fada N’Gourma, Aliero, Kebbi State, and Sokoto, but certain entries like Ribdahu showed stable resistance over all locations. Serious stem borer damage occurred at Gusau and Tsafe, Zamfara state and Samaru, Kaduna state. Severe head bug damage on most Nigerian materials appears to be real limitation to adaptation of these materials in Mali and Burkina Faso. Also, it appears that Nigerian sorghum germplasm is much later than germplasm from equivalent latitudes in Niger, Burkina Faso and Mali, which limits direct transfer of germplasm across countries, even within a specific zone.

F Rattunde, E Weltzien, B Tanimu, I Angarawai,  
K vom Brocke and I. Atokple.

Sweet sorghum germplasm from Mali and breeding materials identified in India were tested in collaboration with the Malian NARS. A set of 100 entries was evaluated at Samanko and at Cinzana for adaptation and productivity. Juice yield and sugar content of these was evaluated at Samanko station only. The different materials flowered over a period of 35 days from mid September to end of October. The sweet sorghum hybrids from India showed higher juice yields than the Indian, and most of the Malian local sweet sorghum varieties. The Malian local varieties had the highest levels of sugar content, which was also positively correlated with juice yield. The data requires more detailed analysis to draw conclusions for further experimentation.

E Weltzien, I Sissoko and F Rattunde

*Output Target 2008 3.1.2: Guinea race sorghum hybrid parents made available to NARS and PS breeders for developing hybrid cultivars*

Sets of male sterile female parents and confirmed restorer lines were sent to eight National Sorghum Improvement Programs in six West African countries in 2007. Male-sterile parents were also sent to ICRISAT-Lilongwe upon request for a PhD study by A. Chamango. The majority of male-sterile parents provided were developed by ICRISAT. Two additional A lines developed by the Malian IER program in the joint ICRISAT-IER Sorghum Hybrid Breeding activities were also provided, with IER agreement, to increase the number and diversity of hybrid combinations for sites in the Northern Sudanian zone. Sets of 21 to 25 identified restorer lines of landrace and bred-varieties were also sent to each National Program for use in producing experimental hybrids representing diverse geographic and genetic backgrounds with zone-appropriate maturity.

**Table. Guinea-race Male-sterile parents provided to National Sorghum Breeding Programs in 2007.**

| Site                      |              |           |                 |                 |              |
|---------------------------|--------------|-----------|-----------------|-----------------|--------------|
| Bambey,<br>Senegal        | ICS38 A      | Fambe A   | 97 SB-F5DT-150A | 02 SB-F5DT-12 A |              |
| Saria,<br>Burkina         | ICS38 A      | Fambe A   | 97 SB-F5DT-150A | 02 SB-F5DT-12 A |              |
| Farakoba,<br>Burkina      | ICS38<br>A/B | Fambe A/B | GP99 271-20 A/B |                 |              |
| Birni<br>N’Koni,<br>Niger | ICS38 A      | Fambe A   | 97 SB-F5DT-150A |                 |              |
| Kano,<br>Nigeria          | ICS38 A      | Fambe A   | GP99 271-20A    | 97 SB-F5DT-150A | IS 3534<br>A |
| Samaru,<br>Nigeria        | ICS38 A      | Fambe A   | GP99 271-20A    | 97 SB-F5DT-150A | IS 3534<br>A |
| Tamale,<br>Ghana          | ICS38 A      | Fambe A   | GP99 271-20A    | 97 SB-F5DT-150A | IS 3534<br>A |

|                     |         |           |                 |                 |  |
|---------------------|---------|-----------|-----------------|-----------------|--|
| Cinzana,<br>Mali    | ICS38 A | Fambe A   | 97 SB-F5DT-150A | 02 SB-F5DT-12 A |  |
| Lilongwe,<br>Malawi |         | Fambe A/B | GP99 271-20A/B  | IS 14414 A/B    |  |

*Output Target 2009 3.1.1: Initial heterotic groupings for sorghum and pearl millet hybrid breeding for WCA established*

A PhD study on “Combining Ability of Inter-racial and Guinea-race Sorghum Hybrid Parents” was initiated in Mali. A total of 50 experimental hybrids were produced in crossing blocks at IER-Sotuba and ICRISAT-Samanko in the 2006/2007 offseason. The experimental hybrids were produced using balanced sets of Inter-racial and Guinea-race parents (three A-lines and 6 R-lines of each group), resulting in Inter-racial x Inter-racial, Inter-racial x Guinea, and Guinea x Guinea hybrids. Yield trials to assess the productivity and adaptation of these hybrids were conducted at IER-Sotuba, ICRISAT-Samanko (Fertile field), ICRISAT-Samanko (Low Phosphorus field), and IER-Cinzana in the 2007 growing season.

Other activities in sorghum towards studying heterotic grouping comprise: agro-morphological characterization of landrace and improved materials and diversity analysis; and production of test crosses using available male-sterile lines and contrasting restorer genotypes in the rainy season 2007.

HFW Rattunde, A Diallo, A Toure and E Weltzien

Activities that contribute important components to the heterotic grouping of WCA pearl millets comprise:

- multi-location evaluation of 100 population hybrids derived from factorial crossing of 20 diverse parental landraces from Senegal, Mali, Burkina Faso, Niger and Nigeria in 2006;
- multi-location evaluation of a complete 7-parent population diallel in 2007;
- creation of further sets of factorial crosses among geographically and/or genetically (based on SSR marker diversity study) distant parental populations in the off-season 2007/08;

BIG Haussmann, S Boureima, NARS partners,  
CT Hash, D Kiambi and D Hoisington

*Output target 2010 3.1.1: New pearl millet and sorghum inbred lines with good combining ability and quantitative trait characterization made available to partners with associated capacity development for developing hybrid cultivars*

Inbred line development in adapted WCA landrace pearl millet materials started in the rainy season 2005 and off-season 2005/06 (production of S1s). Given two generations per year, S4 or S5 inbred generations have been produced in the rainy season 2007. To assess combining ability and the fertility restoration capacity of the materials, various testcrosses were evaluated in 2006 and 2007 (male-sterile lines x original landraces in 2006; male-sterile lines x S3 or S4 lines in 2007). A total of 200 WCA landrace-derived pearl millet inbred lines (in S3 or S4 inbred generation) were characterized for photoperiodic response and for downy mildew susceptibility in the rainy season 2007. The high genetic load in the WCA pearl millet landraces and high inbreeding depression resulted in a loss of certain materials during the course of inbreeding.

BIG Haussmann, S Boureima and H Dodo

Regional research on hybrid sorghum development continues to expand. Analysis of the 11 trials successfully conducted and reporting data from Mali, Burkina Faso, Niger, Nigeria and Senegal in 2006 provide a first examination of adaptation of currently available hybrids over a range of ecosystems (Northern- to Southern Sudanian zones) and sowing dates (June 16 to August 5) and on-farm (3) and on-station (8) conditions. Results from the Southern Sudanian zone (8 trials) indicated that the highest trial means for grain yield (2.4 t/ha) and average hybrid superiority over outstanding local check varieties (27%) were obtained from sowing dates between June 20 and July 10, with decreased yield levels and hybrid superiority in earlier and later dates of sowing. Analyses of 37 new experimental hybrids at ICRISAT-Samanko showed that the highest yielding hybrid (160A x CGM19/9-1-1) produced 4.5 t/ha grain, which was 45% superior to the best landrace check (CSM335). The higher grain yield means obtained with inter-racial x Guinea hybrids (2.8t/ha) versus Guinea x Guinea hybrids (2.7t/ha) and inter-racial x inter-racial hybrids (2.5tha) (two environment means) provided the stimulus for a PhD study on combining ability of available sorghum breeding lines that began in this year in Mali.

Regional Hybrid Yield Trials were expanded in 2007, with 15 collaborative on-station trials conducted in Mali, Burkina Faso, Ghana, Niger, Nigeria and Senegal, as well as five on-farm sites in Mali. Initial Hybrid Observation Nurseries, with an average of 72 experimental hybrids and corresponding parents, were also conducted at a total of 14 sites in the region. Analysis of these trials and nurseries is ongoing.

### **Hybrid Sorghum Seed Production**

Two one-day Hybrid Seed Production Trainings were conducted in Hybrid Sorghum Seed Production plots at ICRISAT-Samanko in 2007. The seed production methods currently under test for producing new photoperiod sensitive hybrid sorghums for West Africa were first presented to the Farmer Cooperative Seed Association (COPROSEM), the supporting NGO, ACOD, and the Umbrella Farmer Organization (AOPP). A second training was conducted for directors of emerging private seed enterprises and representatives of the National Seed Service, AOPP, and the coordinator for a new Foundation Seed Unit in the Malian IER Research Institute. These events raised awareness of advances in both hybrid development and hybrid seed production methods for West Africa, and provide a basis for continued interaction and collaboration to develop commercial seed production of sorghum hybrids in Sudanian West Africa.

The capacity of West African NARS for creating experimental hybrids was strengthened by conducting a West African Sorghum and Pearl Millet Hybrid Breeding Training Workshop at ICRISAT-Samanko, April 17-19, 2007. Sorghum Hybrid Crossing Blocks were prepared and dispatched for seven sites in Senegal, Mali, Burkina Faso, Niger, Nigeria and Ghana. Follow-up visits were conducted during the season in Nigeria, Niger, Burkina Faso and Mali.

F Rattunde, E Weltzien, BIG Haussmann and CT Hash

A PhD dissertation on heterosis patterns in Guinea-race sorghum hybrids was submitted to Cornell University in October 2007. This study assesses combining ability of Guinea-race sorghums of world wide origin. The second PhD study was initiated in Mali at the University of Bamako to assess combining ability of a parental material (male and female pools) currently available in the IER and ICRISAT hybrid breeding programs.

HFW Rattunde, S Dagnoko, A Diallo,  
A Toure and E Weltzien

### **Adaptation of the first generation of guinea hybrids**

In 2006, 5 promising hybrids and one locally adapted check (CSM 335) were tested at 3 plant densities (67, 133 and 200,000 pl/ha) at Samanko and high fertilisation to determine the relationship between the plant density and their potential yield. All the 6 entries flowered within the same week, which indicates their good adaptation to the region of Bamako. AOV on total biomass, grain yield and harvest index shows significant differences between varieties but not between plant densities and no variety by density interaction. However, two hybrids and the local variety tended to yield less at the higher density. Fambé A x CGM 19 had the higher grain yield. At 133,000 pl/ha it produced 18.8 t/ha of aerial biomass and 3.9 t/ha of dry grain, which were +15 and +35% over the local check. Its harvest index was 21.4, 13% over the check, but still low for an improved variety. For all the 6 varieties, tillering was weak at 67,000 pl/ha and quasi-null at higher densities. At harvest the number of remaining tillers was always below 1 at the lowest density and none at higher densities, except for Fambé A x CGM 19 at 133,000 pl/ha where more than at 67,000 pl/ha remained at harvest. The number of grains per panicles was the main factor affected by plant density.

B Clerget and F Rattunde

### **Output 3.2 Improved methodologies developed for integrating breeding of groundnut, sorghum and pearl millet populations and varieties with crop management strategies to overcome key environmental and socio-economic constraints and making them available with new knowledge to partners**

During the year 2007 two output targets, one on training breeders in techniques for breeding hybrids and using tools for farmer participation, and the other on integrated aflatoxin management were achieved as planned, and described in detail below.

An assessment of impact from recent groundnut breeding activities, including farmer participatory variety selection has been completed, and is guiding the new program activities towards more farmer participatory variety evaluations, and decentralized seed dissemination efforts.

The new dwarf guinea varieties derived from the dwarf population are proving to have significantly improved yields over local varieties as controls. These varieties show a better response to fertilizers and generally improved soil fertility, than the local varieties.

Newly established pearl millet population crosses among West-African landraces are now undergoing recurrent selection, involving farmers in mass selection activities.

Integrated *Striga* management research is moving off-station in a substantial manner, by developing a farmer field school curriculum, the appropriate training materials, and conducting technical training programs for trained facilitators. Farmer field schools have been implemented in Mali and northern Nigeria. Farmers are generally very enthusiastic. The results of the integrated management options chosen for each site specifically tends to show clear yield benefits, as well as a reduction in the amount of *Striga* seeds in the soil.

*Output target 2007 3.2.1: Partners from WCA trained in the use of participatory recurrent selection and hybrid breeding techniques (partly associated with the PGRA SWEF).*

A “West African Training Workshop on Hybrid Sorghum and Pearl Millet Breeding” was conducted at ICRISAT Mali during April 17-19 to strengthen regional capacity in hybrid breeding. A group of 39 Sorghum and Pearl Millet researchers from 6 West African countries (Senegal, Mali, Burkina Faso, Ghana, Niger, Nigeria), private seed sector representatives from Nigeria and the United States and an INTSORMIL and a University of Hohenheim collaborator participated in the training workshop. The objectives of the workshop were to strengthen technical skills through systematic review of principals and techniques for successful hybrid breeding, sharing experiences and practical methods for field activities, and identifying priority opportunities and requirements for hybrids in the region.

The formal presentations on heterosis and heterotic groups, combining ability, breeding male- and female-parents, program design of commercial breeding programs, and information on key panicle, grain and flowering response traits required for adaptation. Participants also shared experiences in field observations, crossing techniques and parental seed multiplication. The group concluded the workshop with discussion of future activities and potential funding for their implementation. Regional collaboration was identified as a key requirement for success in this endeavor, and strong willingness to exchange germplasm and conduct joint testing was expressed.

The workshop proceedings are published.

A training program on participatory recurrent selection was held in Segou during 8-17 September 2006 with 23 participants including NARS pearl millet and sorghum breeders, development workers, farmers’ organization representatives, plant breeding students and research technicians. The course focused on three thematic areas:

(i) Priority setting, and identifying specific objectives for a breeding program: The group discussed the different issues for which a plant breeding requires priorities, such as the target environment and production system, base germplasm to be used, selection criteria and roles and responsibilities of the different partners. The discussion of different methods for recurrent selection of pearl millet and sorghum took up a large part of the course, constantly examining options for farmer involvement in the decision making process. Each country group planned activities for their sites, and with the material available to them, involving the various partner organizations.

(ii) Communication tools specifically useful for participatory breeding projects and their orientation: The participants had a chance to put their communication skills into practice during a visit to some of the villages where IER scientists were working near the Cinzana research station.

(iii) The organizational and institutional options for planning and implementing a participatory recurrent selection program were another thematic area for intense discussions. We examined the organizational set-up of the IFAD funded investment projects for achieving farmer capacity building to enable them to achieve higher production, and improve their access to markets. Similarly the farmer organizations described their approaches to creating innovations and other benefits for their members. This session was particularly important for the planning of PROMISO project activities, as this project does not envisage creating new models of farmer researcher interactions, but rather builds on existing experiences, institutions, and investments into strengthening local organizations, and innovation processes.

An additional group of four breeders from WCA partner countries were trained together with scientists, extension workers and farmers from the Eritrean national pearl millet program, during a training course held in Eritrea, focusing on pearl millet.

E Weltzien, HFW Rattunde, CT Hash,  
BIG Haussmann and K. vom Brocke

### **A report on Farmer participatory evaluation and dissemination of groundnut varieties in West Africa published**

The demand for varieties by farmers and oil processing industries is a result of plant, seed, and other desirable traits that are embodied in the varieties. Knowledge of the range of plant, seed and processing traits are valuable for crop improvement programs and good market signals for processors. The demand for improved groundnut varieties will increase if varieties are designed to include producer and consumer preferred traits. Therefore, improving the performance of varieties accounting for all significant traits will contribute to the productivity and profitability of groundnut.

The main objectives of the farmer participatory variety selection (FPVS) evaluation were: 1) to identify farmers' preferred traits and varieties and 2) to test a range of seed multiplication and delivery schemes. A report documenting the results from FPVS trials conducted in Mali, Niger, Nigeria and Senegal in 2003-2004 crop seasons and a range of seed multiplication and delivery schemes in 2005-2006 was completed and will be published as proceedings of a workshop on Development of sustainable Groundnut Seed Systems in West Africa. This is expected to be published before the end of December 2007. The report documents the pathways to adoption of improved groundnut varieties, the lessons learned and the perspectives for enhancing variety adoption. The key highlights of this report are as follows:

Among the 39 varieties evaluated across the four countries, 17 were selected and are being used. The varieties selected were: ICG 7878, Fleur 11, JL 24, ICG [FDRS] 4 and Mossitiga in Mali; ICG 9346, RRB, J11 and T 81-73 in Niger; SAMNUT 21, SAMNUT 22 and SAMNUT 23 or ICGV-IS 96894 in Nigeria and ICGV 86124, ICGV 89063, PC 79-79, H 75-O and 55-33 in Senegal. In Mali and Nigeria, all the varieties have been released while in Senegal, the selected varieties are candidates for formal release.

Preferred traits included early maturity, high pod and fodder yield, resistance to diseases, seed color, taste, oil content, tolerance to drought and marketability. Preference often differed among the sites, which reflected differences in agro-ecological zones. In each location farmers selected at least two improved groundnut varieties based on some of these traits.

More than 30 farmers' associations and small-scale seed producers were involved in seed production and distribution of selected varieties. More than 150 tons of seed of different classes that could cover 100,000 hectares were produced. About 74% of the farmers in pilot areas are using modern varieties, and about 67% of the groundnut area is planted with them.

In locations where FPVS was limited to providing only seed for experimentation without ensuring seed supply such as in Mandé and Dioila in Mali, the proportion of the area covered with improved groundnuts was low (28%), whereas in locations where FPVS was implemented in conjunction with setting up institutions and institutional arrangements to supply seed to farmers (such as in Kolokani, Mali), the uptake in areas around the pilot sites was estimated at 83%.

Lessons learned are that FPVS has been successful in identifying varieties preferred by farmers, and accelerated their dissemination. They also empower farmers to select new varieties under their own management and criteria. The trials were also a source of good quality seed and farmers' hands-on training in seed production and variety maintenance. Individual farmers and farmers' associations willing to produce and supply seed have emerged in the pilot areas and are promising options for a sustainable community-based seed system. These programs need to be replicated in other target areas in collaboration with partners who have established links with farming communities there.

The participatory approach has led to the rapid spread of groundnut varieties among farmers in the villages surveyed. This suggests that resource-poor farmers are constantly in search of new opportunities to diversify their income source to improve their well-being. Technologies that have a comparative advantage in farmers' agro-ecological and socioeconomic conditions that provide new opportunities for income generation and

diversification are critical. When a technology is appropriate, it stimulates an endogenous process of auto-diffusion through a dynamic farmer-to-farmer horizontal spread of planting material. Thus, adoption coupled with building of seed supply systems is crucial.

B Ntare, J Ndjeunga, F Waliyar, O Kodio,  
CA Echekwu, I Kapran and A DaSylva

*Output target 2008 3.2.1: Diversified dwarf Guinea-race sorghum population and broad based pearl millet populations with farmer –preferred traits made available with associated capacity development to partners for the first time for different SAT agro-ecologies in WCA (partly associated with SLP SWEF).*

Dwarf Guinea Sorghum Population progenies, dwarf breeding lines, and superior local landrace varieties from Burkina Faso were inter-mated in crossing blocks at INERA-Saria, IER-Sotuba, and ICRISAT-Samanko in 2006. The F1 bulks (bulked by male parent) of crosses made in Burkina Faso are sown for observation and generation advance in INERA-Saria, IER-Cinzana and ICRISAT-Samanko in 2007.

A total of 28 bi-parental F1 crosses of Dwarf Guinea Population from IER inter-racial varieties are being tested for yield performance and agronomic desirability in three replicate trials at IER-Sotuba and ICRISAT-Samanko in 2007.

F2 populations of the 28 Guinea-Population x Inter-racial bi-parental crosses were sown at ICRISAT-Samanko in isolation in 2007 for recombination. The progenies were sown in randomized order in four replications to maximize recombination.

Population improvement of the original Dwarf Guinea Population was continued through a) testing productivity and agronomic desirability of 37 progeny bi-parental crosses in a two replicate trial at ICRISAT-Samanko, and b) recombination in isolation, with eight F2 bulks (based on female parent) sown in alternating rows with an F1 bulk of all crosses made in 2006. Pollen from the F1 bulks provides better sampling of the original 20 progenies that were crossed. The male-sterile plants in the F2 were identified for creating the Cycle 2 bulk.

HFW Rattunde, E Weltzien, K vom Brocke and A Toure

With regard to pearl millet, five broad-based populations targeting different agro-ecological zones were created at ICRISAT-Sadore through diallel crossing in the off-season of January-April 2007. Parental materials consisted of 3 to 4 diverse landrace accessions selected by farmers at the 5 pilot sites in the rainy season 2006, and the local cultivar commonly preferred at the respective pilot site. Target pilot sites in this activity were: Tera (Tillabery region), Falwel (Dosso region), Serkinhoussa (Maradi region) and Lelehi (near Niamey) in Niger and Dioura in Mali. While extra-early materials were employed at Dioura, early- to medium-maturity materials were needed for the other sites. The first cycle of mass selection was performed by the partner farmer organizations in the rainy season 2007.

BIG Haussmann and partner organisations

*Output target 2008 3.2.2: Tools for effective integrated Striga management for different agro-ecologies made available to partners.*

### **Training**

The participation of farmers in developing and evaluating integrated *Striga* management is essential for the adoption of appropriate ISM strategies and wide-scale control of *Striga*. In this process, knowledge and the capacity to install, observe and evaluate trials for integrated control of *Striga* are essential for farmers and technicians. Six NARS scientists, 20 agricultural extension workers, 240 farmer trainers and 750 farmer participants participated and/or were trained in experimentation, observation, discussion and acquired knowledge on promising agronomical practices, *Striga* biology and potential control options.

Furthermore, two NARS scientists (Maina Ibn. Mohammed (LCRI, Nigeria) and Alain Paul Andrianaivo (FOFIFA, Madagascar)) were trained in “*Striga* seed laboratory techniques” at ICRISAT-Sadore station in October 2007. These techniques include extraction of *Striga* seeds from soil samples for assessing *Striga* seed densities in farmers fields, *Striga* seed viability and germination tests.

### **Seed bank dynamics model for *Striga hermonthica* developed**

Research on *Striga* and control of *Striga* are very costly and long-term monitoring of the effects of control strategies on *Striga* seed bank dynamics is very unpractical. Therefore it is useful to develop a model that can project long-term effects of control methods that have been evaluated for a limited number of years. A *Striga*

seed bank model for simulation of long-term effects of control strategies on *Striga* seed bank dynamics and host cereal yield has been developed, parameterized and simulations have been performed. The results have led to a manuscript that has been accepted by Weed Research. The data from current on-station experiments and literature will feed into the model and the long-term effects of ISM options will be simulated. These results will aid in the development of promising short-term and long-term practices and control measures and ISM. There are also plans to expand the model to include a more advanced crop growth module and add a soil module.

### **On station trials on integrated management and population dynamics of *Striga hermonthica***

On-station trials investigating the efficiency of individual and combined control techniques to reduce the *Striga* seed bank and increase crop yields were conducted in Samanko (Mali) and Sadore (Niger) in 2006 and 2007. Different control techniques and combinations evaluated were: local susceptible cereal variety (control), *Striga* resistant cereal variety, and addition of organic amendments, intercropping cereal with cowpea, a combination of intercropping and organic amendments and a combination of intercropping, organic amendments and resistance. Preliminary analysis indicates that individual control techniques show variable *Striga* suppression over years and that a combination of control strategies appears very promising and can reduce the number of emerged *Striga* plants and seed production to less than 10% compared to a local susceptible variety. A combination of intercropping, organic amendments and resistant variety yields higher cereal biomass and grain yield than the local susceptible variety. Furthermore, the cowpea intercrop produces a large biomass that can be used as fodder. Cowpea seed production remains dependent on labor intensive insecticide spraying of the cowpea crop during flowering and pod setting. Weeding could still be added to an integrated control package to reach nearly 100% reductions in emerged *Striga* plants and zero seed production.

Furthermore, interactions between host resistance, *Striga* seed bank density and organic amendments are being determined. In 2007, the experiments were repeated for a second year. Results from these on-station trials will be translated in recommendations for farmers within the ISM-FFS participatory research and the farmer field school framework.

### **On-going activities**

#### *A manual for implementation of ISM farmer field schools*

A second draft of a manual for FFS for *Striga* (and Cowpea) management in English is ready. Later, a French version will appear. This will become an IPG for use by extension workers, NGO's and NARS throughout sub-Saharan Africa in the dry sorghum and millet cropping systems.

#### *Farmer Field Schools for Integrated Striga Management (ISM)*

More than 60 participatory trials investigating integrated *Striga* management were installed within a farmer field school set-up in Mali (Douentza (6) and Tominian (8)) and Nigeria (Sokoto (3), Kebbi (15), Katsina (14), Zamfara (6), Jigawa (3), Yobe (7) and Borno (3) state). Agronomic, economic and knowledge transfer data is currently being gathered at all sites.

#### Intended users:

NARS (LCRI and IAR, Nigeria; IER, Mali; INRAN, Niger)  
CBO/FO (CBARDP, Nigeria; AOPP, Mali)

#### Outcome

Strengthened partners (NARS and CBO) in participatory testing of ISM. Strengthened farmers (trainers and participants) in experimentation, knowledge of *Striga* and its control, insect pests and agronomic practices.

T van Mourik, H Dodo, E Weltzien and BIG Haussmann

*Striga* resistance in farmer preferred cultivars of sorghum in Mali is being enhanced using marker assisted selection. Two varieties widely grown and in increasing demand have been used as recurrent parents. The IER sorghum program in collaboration with the biotechnology laboratory of the University of Bamako and the Beca Bioscience facility in Nairobi, Kenya identified a set of 32 BC2S3 lines that carry at least one of the three QTLs originally identified using the resistant variety N13 as a source. The evaluation of the effective *Striga* resistance in the backcross lines with different numbers of *Striga* resistance alleles present was conducted under farmer field conditions with naturally high levels of infestation, and under artificial *Striga* infestation at Samanko and Sotuba stations. At Samanko three experienced farmer seed producers evaluated all the entries for their resemblance to the two recurrent parents used in the backcrossing. Results are presently being analyzed.

A Toure, O Koita, D Kiambi, F Rattunde,  
I Sissoko and E Weltzien

*Output Target 2008 3.2.3: Survey on the adoption and impact assessment of groundnut improvement research in WCA completed*

The major constraints facing the development of the groundnut sector in West Africa are known to be, among others, the poor access and availability of high yielding groundnut varieties resistant to the rosette virus and foliar diseases. Since the 1990s, ICRISAT and partners – Institute for Agricultural Research (IAR), Institut d’Economie Rurale (IER) and Institut National de Recherche Agronomique du Niger (INRAN) – have developed or introduced a range of groundnut varieties with various attributes including different maturity groups resistant to groundnut rosette disease, foliar diseases and other desirable agronomic traits. About 39 varieties have been selected from regional variety trials across a range of agro-ecological zones.

During the 2003 and 2004 cropping seasons with funding from the Groundnut Seed Project (GSP), a program of more than 200 Farmer Participatory Variety Selection (FPVS) trials in Nigeria, Niger and Mali was implemented. Following the choice of varieties by farmers, ICRISAT and partners initiated and catalyzed the development of organizations and institutional arrangements that will deliver seed at low transaction costs to smallholder farmers. Research institutes were involved in the production of breeder and foundation seed using revolving fund schemes. Similarly more than 30 farmers’ associations and 20 small-scale farmers were trained in seed production and marketing. This resulted in the production of more than 33 tons of breeder seed and 107 tons of foundation seed. In addition, more than 130 tons of certified seed have been produced by community based organizations. This amount of seed could cover more than 100 000 ha of groundnut. However, little is known on whether the modern varieties have spread beyond the FPVS participants and the pilot sites, whether the area cultivated to modern varieties has increased in the pilot sites, whether the number of households using modern varieties have increased, what the major drivers are for the uptake of modern varieties and the options of scaling up and out such technical and institutional interventions.

This study was conducted to assess the level of adoption of modern varieties and compare it with baseline information in the pilot sites; identify the determinants of uptake and intensity of adoption of modern varieties, and propose options for scaling up and scaling out successful innovations.

Surveys were conducted between December 2006 and Feb 2007 to investigate the early adoption of modern groundnut varieties in pilot sites, and neighboring villages. Overall, 1190 households (343 in Mali, 370 in Niger and 470 in Nigeria) were selected and interviewed. These included 868 households in pilot sites and 322 in neighboring villages. Of the households in the pilot sites, 450 were trial participants and 418 non-participants. Seventeen varieties were disseminated in the pilot sites of the three countries. The results show diffusion and adoption of groundnut varieties increased significantly in the pilot sites in the three years, using 2003 as baseline. The rate of adoption increased from 10 to 32% in Nigeria, from about 32 to 44% in Mali and from 3 to 13% in Niger. Varieties have spread beyond the pilot sites. In Mali, 88.52% households’ who participated in the on-farm trials are growing modern varieties, 56.91% among non-participants in the same villages and 43.43% in the neighboring villages. A similar pattern has been observed in Niger and Mali.

Since 2003, the proportion of area planted with modern varieties in pilot sites has increased by 22% in Nigeria, 12% in Mali and 10% in Niger. Farmers using modern varieties have derived significant yield gains of 24%, 43% and 31% over the local varieties in Mali, Niger and Nigeria, respectively. The modern varieties had significantly lower per unit cost of production estimated to be 9.8%, 11% and 11% in Mali, Niger and Nigeria, respectively. This percentage unit cost reduction was moderate and indicates that yields are still very low. This is explained by the low use of inputs such as fertilizers to boost yields under farmers’ conditions. The net income derived by adopters is 66% higher than non-adopters in Mali, 73% in Niger and 111% in Nigeria.

Results from the Logit model analysis indicate that the major determinants of adoption in the three countries include the participation of farmers in on-farm trials and the build up of social capital through the empowerment of farmers’ associations and small-scale farmers producing and marketing seed. Constraints to adoption remain the poor access and availability of seed of modern varieties and pest and disease pressure in at least two of the three countries. Tobit results indicate that intensification of modern varieties is dependent essentially on seed availability, social capital and exposure to varieties through farmers’ participatory variety trials.

Thus, the major drivers of adoption were identified as exposure of farmers to modern varieties via on-farm trials, the development and empowerment of farmers’ associations, the involvement of small-scale seed producers tasked at producing seed of preferred varieties and the involvement of research institutes in supplying



breeder and/or foundation seed. Seed access and availability, pest and disease problems and credit constraints too play a crucial role.

To realize the full benefits of modern groundnut varieties, farmers in West Africa would have to adopt management practices that will significantly increase yields. There is still a wide gap between farmers' realized productivity and grain and fodder yields on-station. In addition, there is a need to develop groundnut markets. Though farmers are not complaining about selling their products in domestic markets, the price they receive is often low.

Questions remain as to the capacity of the domestic groundnut market to absorb additional production. There is also a need to address aflatoxin issues through the use of proper crop management technologies and storage infrastructure so as to enlarge the demand base to allow farmers to access regional and international markets. Adoption of modern groundnut varieties will be enhanced if governments and donors could invest more in the development of institutions and institutional arrangements that will deliver seed at affordable cost to smallholder farmers. Arrangements are required to facilitate farmer access to credit and to organize farmers through collective actions so that they benefit from the sale of their products.

Policies and institutional innovations that enhance opportunities for farmers to experiment with varieties and select those with preferred traits, followed by the development of village seed supply and delivery schemes are essential drivers of adoption of modern groundnut varieties in West Africa.

J Ndjeunga, B Ntare, F Waliyar, CA Echekwu, O Kodio,  
I Kapran, AT Diallo, HY Bissala and A DaSylva

*Output Target 2009 3.2.1: First availability of allele-specific molecular markers for genes controlling photoperiod sensitivity of flowering time in pearl millet and sorghum*

To precisely assess the photoperiodic reaction of diverse sets of materials ("phenotyping"), 200 pearl millet inbred lines ( $\geq$ S3 inbred generation) and 210 sorghum lines were grown in the rainy season 2007 at Sadore (Niger) and Samanko (Mali), respectively, using two planting dates and two replications per planting date. Special care was taken to determine days to first and 50% flag leaf appearance and days to first and 50% flowering. Data analysis is underway. Leaf samples were taken from all the phenotyped accessions and sent to the partner group at University of Hohenheim, Germany for DNA extraction. Simultaneously, the Hohenheim partners were able to sequence 10 candidate genes for sorghum and 5 candidate genes for pearl millet. Assessment of population structure and analysis of SNPs in the phenotyped materials is currently underway.

BIG Haussmann, F Rattunde, E Weltzien, B Clerget,  
R Pasam, S Bhosale, HK Parzies (Hohenheim University)

*Output Target 2009 3.2.2: New Striga-resistant genepool of pearl millet available for testing in West African breeding programs*

Remnant seed of full-sib (FS) and S1-progenies selected from the 2006 *Striga* resistance trials was used to create new sets of 164 full-sib and 91 S1 progenies in the off-season January-April 2007. A second cycle of recurrent full-sib and S1-progeny selection for *Striga* resistance and grain yield was then performed at ISC in the rainy season 2007. Thirty-seven new accessions were included in the FS trial 2007 to enable further diversification of the genepool with new, less sensitive materials. Mainly due to late onset of the rains and resulting late planting, *Striga* infestation was comparatively low on the 2007 trials. Data analysis is underway.

BIG Haussmann

*Output Target 2009 3.2.3: Knowledge of adaptation and validated regional adaptation maps for sorghum and pearl millet made available and disseminated with associated capacity development to WCA partners*

### **Genotype by environment analysis of pearl millet landraces**

During the period from 2006 to 2007, the pearl millet improvement program created several data sets for a genotype x environment interaction based adaptation mapping. The most appropriate data series will be on 72 early- to medium-maturity landraces evaluated at six locations (from Senegal to Nigeria) over two years (2006 and 2007), allowing for separation of genotype x location *versus* genotype x year interactions. Another series comprises 32 late pearl millet accessions evaluated at 3 locations over 2 years. Fifteen extra-early materials evaluated at 5 locations in 2007 provide initial insights in genotype x environment interaction and potential adaptation of these materials. Data analysis is underway.

### **Variety adaptation maps based on maturity dates, and the end of the growing season**

Mapping tools have been adapted to indicate zones of varietal adaptation based on estimated ending dates of the rainy season, using long-term weather data. The availability of weather data has improved, by adding data from Nigeria, northern Benin and other coastal countries. Thus the maps for West-Africa are becoming rather complete. Varietal adaptation based on the predicted end of the growing season, and the flowering response of the varieties has been mapped for a set of 25 varieties, that have been released for cultivation in the region. These maps are currently proposed and explained to breeders of the region. They will constitute a good support to explain to variety users the region of adaptation of each realized variety.

B Clerget, BIG Haussmann, I Maikano and PS Traore

### **Comparing the aerial and root development of pearl millet, sorghum and maize**

An experiment comparing aerial and root growth of sorghum and maize was initiated in 2005, and has been further pursued in 2006, by adding also pearl millet. Locally cultivated varieties of all three species were sown on 27 June, 12 days later than in 2005. The kinetics of leaf initiation were linear and faster for maize than for pearl millet and, lastly, for sorghum. Kinetics of leaf appearance was linear for maize and bilinear for pearl millet and sorghum. The initial slopes were equal for maize and pearl millet and larger than for sorghum. Maize produced no tillers, sorghum produced on average one tiller and pearl millet 7 to 8. The number of tillers decreased during jointing for both species and also during grain ripening in pearl millet. The plant height and vertical root growth rates were equal for maize and sorghum and a little larger for pearl millet, in agreement with the 2005 data. The horizontal root growth rates were equal for pearl millet and maize and lower for sorghum, in disagreement with the 2005 results. Thus the vertical root growth rate is estimated between 2.5 and 3.0 cm/day in sorghum and maize and is faster in pearl millet (3.5 cm/day). The horizontal root growth is between 1.2 and 1.8 cm/day with no significant difference shown between species.

The life cycle durations were 87, 122 and 128 days in maize, pearl millet and sorghum respectively. The total aerial dry biomass yields were 12.6, 17.9 and 20.7 t/ha. The root biomass yields were 1.2, 3.0 and 4.4 t/ha and the dry grain yields were 4.6, 3.0 and 2.8 t/ha. In maize, the stem biomass decreased between flowering and maturity while it increased in the main stem of sorghum and pearl millet during the same phase. This pattern is related to the stay-green trait observed in local sorghum and pearl millet varieties, which have stems that remain green and strong at harvest and later on, while maize stems are dry and fragile at that time. It is because maize stem reserves are translocated to the maturing grain whereas on the contrary pearl millet and sorghum stems continue to accumulate photosynthate during this period.

B Clerget

### **Dates of panicle initiation of sorghum and pearl millet varieties in Bamako and Montpellier**

As a part of the multi-latitudinal trials conducted to observe the effect of the latitude on the photoperiod-sensitive reaction, 5 sorghum and 5 pearl millet varieties, chosen for their contrasted photoperiod-sensitivity, were sown simultaneously in Bamako (Mali, 12°N) and Montpellier (France, 43°N), in May, June and July 2006. The dates of panicle initiation were generally later at the higher latitude, excepted for IRAT 204, a non photoperiod-sensitive variety, and for Souroukokuou, very late and photoperiod-sensitive. Panicles of both varieties were initiated at the same date in both locations. In Souroukokuou, the event took place around the autumn equinox, on 21 September, for the 3 sowing dates and 2 locations. In Bamako the dates of panicle initiation observed in 2006 were about one week later than predicted from the previous observations (2000 to 2004) for 2 sorghum varieties, CSM 335 and Sarioso 10. But above all, in Montpellier, panicle initiation of Sarioso 10 occurred 33, 20 and 3 days later than predicted from the 2001 results. Consequently it appears an inter-annual variability of the date of the panicle initiation that is much higher than expected, at least at high latitude. In France it has been observed that the flowering date of some varieties had been delayed by the warm, above normal, temperatures of June and July 2006. The panicle initiation of Sarioso 10 could present a high sensitivity to temperature.

B Clerget

#### *Output Target 2010 3.2.1*

*Tools for farmer participatory recurrent selection tested for pearl millet and sorghum with partners with associated capacity development in different agro-ecologies*

In villages where the IER and ICRISAT have been collaborating with farmers on conducting variety trials, we could identify expert farmers, with a keen interest in variety testing and panicle selection. To move forward

rapidly with the identification of new varieties from new population crosses made recently we have initiated farmer selection plots for mass selection in diversified population bulks. Farmers are selecting both sterile and fertile plants. Another set of farmers with the same skills and interest is growing a range of different S2 and S3 nurseries, in which they are selection between rows, and between plants within rows. Farmers selections will be used to select OPV's from further in-breeding, and to random-mate new cycle bulks, and possibly new crosses.

With the side aim to further recombine the five diversified pearl millet populations, on-farm recurrent selection was limited to simple mass selection in 2007. Full-sib selection trials will be initiated with selected farmer groups at the pilot sites in 2008, and compared to progress made by simple mass selection.

E Weltzien, BIG Haussmann and F Rattunde

#### *Output target 2010 3.2.2*

*Three NARS empowered to breed groundnut varieties with multiple attributes especially drought tolerance*

*Milestone: Evaluation of diverse breeding populations to groundnut rosette disease*

Groundnut rosette is the most destructive disease of groundnut in sub-Saharan Africa. Improved resistant varieties of short- medium- and long-duration have been developed but many are highly susceptible to the most important foliar diseases (early and late leaf spots and rust). A total of 165 F4-F6 breeding populations combining early maturity and rosette resistance, rosette resistance and aphid vector, resistance to rosette and early leaf spots, were grown at Samanko for generation advance. Single plant and bulks were selected based on pod yield and other agronomic characteristics. Selected bulks and lines will be evaluated under imposed rosette pressure in Nigeria in the 2008. Breeder seed of 20 varieties and elite lines was produced at Samanko. These involved 9 popular varieties in Mali, 6 aflatoxin tolerant lines, 5 drought tolerant lines and 10 confectionary types. Seed quantities (pods) ranged from 3 to 260 kg.

BR Ntare and AT Diallo

*Milestone: Advanced breeding lines with combined resistance to groundnut rosette disease, aphids, early and late leaf spots evaluated for yield performance (2007)*

During the 2007 crop season, a total of 223 F7-F8 advanced breeding lines with desirable agronomic and quality characteristics (plant type, pod shape, seed size and color), combining resistance to groundnut rosette and other attributes such as aphid vector resistance, limited fresh seed dormancy and foliar diseases were evaluated in 5 replicated (2 replications) preliminary trials at Samanko, Mali. Harvesting was completed by the end of October and samples are being processed for post harvest data capture. The severity of early leaf spot was very high and very few lines were tolerant to the disease. Selected lines will be made available to NARS in Mali, Niger, and Nigeria in the 2008 crop season. Selected lines will also be screened for rosette resistance in a rosette disease nursery in Nigeria.

B Ntare and AT Diallo

*Milestone: breeding lines resistant to foliar diseases and aflatoxin contamination available to NARS in WCA (2008)*

Groundnuts are prone to infestation by two closely related fungal species, *Aspergillus flavus* and *A. parasiticus*. Both fungal species produce a highly toxic group of mycotoxins known as aflatoxins. Health effects in humans and livestock due to consumption of aflatoxin-contaminated foods include impaired growth, liver and other cancers, immuno-suppression, synergisms and death. These toxins can contaminate an array of crops including maize, groundnuts, spices and tree nuts. To minimize aflatoxin contamination a combination of host plant resistance and best bet pre-and post-harvest crop management are being refined. Breeder seed of six advanced breeding lines having resistance to foliar diseases and tolerant to aflatoxin contamination was produced at Samanko. This seed will be used in farmer participatory variety trials using a mother and baby design in 2008 crop season. In addition, 20 advanced breeding lines tolerant to Aflatoxin contamination were obtained from ICRISAT-Patancheru. These were in an observation nursery at Samanko, Mali. They will be evaluated in a preliminary evaluation trial for yield in 2008 and promising lines made available for selection by NARS partners.

B Ntare and AT Diallo

**Output 3.3 Crop management, *Aspergillus flavus* resistant groundnut varieties and post-harvest technologies to reduce aflatoxin contamination in food and feed products, as well as micronutrient rich cereal varieties and processing techniques to improve bio-availability developed, tested and made available to partners with new knowledge in the SAT of WCA**

The work on aflatoxin management is at a point where dissemination of the knowledge and tools will be crucial in terms of improving farmers' and consumers' well-being, and creating new export opportunities. Market sampling of groundnut products has shown that levels of aflatoxin contamination, especially in groundnut paste, but also in nuts is very high, so that this food poses a real and threatening health risk. Thus consumer and health workers' awareness needs to be raised. It seems crucial to also work directly with traders and others involved in the handling of groundnuts for sale, as much of the increased contamination appears to be happening post harvest and off-farm.

The research on iron and zinc nutrition, and the role pearl millet and sorghum play has been now taken up with full force. Careful consumer survey work, including 24 h observations have been conducted in key sites. The poor nutritional and health status of young children, reported through national statistics, could be confirmed on a local level. Children's diets are very strongly dominated by cereals. They tend to lack in proteins as well as crucial minerals and vitamins. In many cases, even the caloric needs of young children are not regularly met. Thus collaboration with the health services, development organizations with health and nutrition experiences is crucial for rapid and lasting impact.

*Output Target 2007 3.3.1*

*Integrated aflatoxin management practice knowledge distilled and disseminated to partners*

Groundnuts are prone to infestation by two closely related fungal species, *Aspergillus flavus* and *A. parasiticus*. Both fungal species produce a highly toxic group of mycotoxins known as aflatoxins. Health effects in humans and livestock due to consumption of aflatoxin-contaminated foods include impaired growth, liver and other cancers, immuno-suppression, and death. These toxins can contaminate an array of crops including maize, groundnuts, spices and tree nuts.

ICRISAT and partners in WCA have developed several technologies that can reduce risks of aflatoxin contamination in groundnuts. These include genetic resistance and integrated crop management practices, agronomic practices, biological control and biotechnological interventions.

Five resistant/tolerant cultivars were evaluated by 10 farmers in five villages of Kolokani district of Mali under their own management practices over a period of three years (2004-2006). A number of agronomic practices that minimize risk of pre-harvest infection by *Aspergillus flavus* were tested in two major groundnut growing areas in Mali (Kolokani and Kayes) (2003-2005). These technologies included the application of lime, farmyard manure (FYM), crop residues (CR) and their combinations using an aflatoxin resistant (55-437) and a susceptible (JL 24) cultivar.

Several appropriate harvesting and drying techniques, such as avoiding damage to pods, harvesting at maturity, proper drying of pods immediately after harvest were also tested in farmers' fields and demonstrated in Kolokani and Kayes (Mali); Samaru in Nigeria and Kaolack in Senegal. Aflatoxin contamination was monitored in market samples of groundnut products from Mali.

The key results of the all the aflatoxin management work are as follows:

The tolerant varieties showed significantly lower levels of *A. flavus* infection and aflatoxin contamination compared to the susceptible control varieties. For example, ICG 6101 and ICG 7 recorded low aflatoxin content of <1.0 µg/kg compared to 1.02 µg/kg for the resistant variety 55-437 and 92.49 µg/kg for the susceptible variety Fleur 11. The results confirm the tolerance of these varieties to aflatoxin contamination. Thus they can play a significant role in the integrated management for reduction of aflatoxin in foods prepared from groundnuts.

Among the agronomic practices tested and demonstrated, the application of lime was the most effective; it reduced contamination by 73% and 85% at Kolokani and Kayes, respectively. A combination of farmyard manure and crop residues reduced aflatoxin contamination by 46-74% compared to the control treatment.

Best-bet harvesting and drying techniques such as avoiding damage to pods, harvesting at right maturity, proper drying of pods led to a significant reduction in aflatoxin contamination ranging from 69 to 88% in Kolokani and from 63 to 84% in Kayes, in Mali. Similar results were obtained in Nigeria.

On an average, 55.3% of the farmers who participated in the on-farm trials produced groundnut with less than 10 µg/kg aflatoxin compared to 7% of non-participants.

High levels of aflatoxin were recorded in samples (kernels and paste) collected in various markets in Mali. Out of 360 samples, only 14% had aflatoxin contents of less than 20 µg/kg. Aflatoxin contents of over 2000 µg/kg were also recorded.

The general conclusion from these results is that while it is possible to control aflatoxin contamination at the production and harvest levels, the causal agent (*Aspergillus flavus*) seems to represent a major problem at the transport and storage level. Thus proper handling is equally important. The on-farm results need to be scaled-up and out to larger geographical areas and include appropriate mechanisms and linkages to leverage changes in policy and institutions to effectively address marketing constraints and health concerns for local consumers. However, this requires additional resources.

A syntheses report documenting the results, experiences and lessons learned was compiled, edited and is being prepared for printing. This will be distributed to partners.

A regional dissemination workshop was held in Bamako, Mali, from 2-3 July 2007 to present the results of the just concluded project on the “Development of Sustainable groundnut seed systems in West Africa”. Measures to minimize aflatoxin contamination were a major component of the project. A paper on on-farm management of aflatoxin contamination was presented and will appear in the proceedings of the workshop being prepared for printing. Forty six (46) participants including the key actors along the value chain (researchers, farmers, traders, processors and policy makers) attended the workshop. Other dissemination pathways have been through flyers, brochures in various languages (English, French, Bamabara and Hausa). These have been widely distributed in Mali, Niger, Nigeria and Senegal.

BR Ntare, F Waliyar AT Diallo, O Kodio and B Diarra

#### *Output target 2007 3.3.2 Human mineral nutrition (Fe, Zn) and role of sorghum and pearl millet assessed in Mali*

Malnutrition is a serious problem in the semi arid tropics where sorghum and millet are the staple crops. The contribution of cereals to the overall diet in terms of energy is extremely important, but there is not much known about the importance of these crops for mineral nutrition and on the current practices with regard to grain processing, food preparation and eating practices. Therefore, the consumption of sorghum and millet and its contribution to mineral nutrition was assessed by a study compiling and synthesizing existing literature of Mali, Burkina Faso and Niger. The findings stress the importance of cereals to the overall diet in West Africa, providing 67-90% of the energy intake and 67% of the iron intake. The food consumption does not meet the nutritional needs, in particular for children under five. The main reasons for the inadequacy of the diet are the low bioavailability of minerals from cereals, low energy density of complementary food, non-availability of foods and food habits. The recommendations of the report include the further development and introduction of improved sorghum and millet varieties with a higher iron and zinc bioavailability, dietary diversification, and improved transformation of cereals in order to increase mineral absorption and energy density. The report “Millet and Sorghum Consumption and Contribution to Human Nutrition in Mali, Niger and Burkina Faso – With Specific Focus on Micronutrients” is published in French and English and distributed amongst partners and continues to be available.

In order to complete the picture on the role of sorghum and millet in human nutrition, a study on individual level food intake took place in 12 households in the zones of Mandé, Dioila and Tenenkou. The study aimed to assess dietary intake and to complement current household food consumption data. The study estimates revealed that cereals provide more than 74% of the dietary iron and 84% of the dietary zinc. Cereals are consumed in the form of thick paste, couscous or porridges and accompanied by a low nutrient dense sauce. Therefore, the high cereal contribution to mineral intake is mainly due to the low diversity of the diets.

#### *Output Target 2008 3.3.1*

*Technology adoption studies on uptake of aflatoxin contamination avoidance completed*

Information on households who participated in the on-farm trials demonstrations has been collected during the course of surveys on early adoption of groundnut varieties in Mali. Those households who conducted participatory trial on minimizing aflatoxin contamination will be interviewed in 2008 and report prepared.

*Output Target 2009 3.3.1*

*2-3 farmer-and market preferred groundnut varieties resistant to aflatoxin contamination recommended for release with associated capacity development by NARS in WCA*

To minimize aflatoxin contamination a combination of host plant resistance and best bet pre-and post-harvest crop management technologies are being refined in groundnuts. Breeder seed of six advanced breeding lines having resistance to foliar diseases and tolerant to aflatoxin contamination was produced at Samanko. This seed will be used in farmer participatory variety trials using a mother and baby design in the 2008 crop season. In addition, 20 advanced breeding lines tolerant to Aflatoxin contamination were obtained from ICRISAT-Patancheru. These were in an observation nursery at Samanko, Mali. They will be evaluated in a preliminary evaluation trial for yield in 2008 and promising lines made available to NARS.

*B Ntare, AT Diallo*

*Output Target 2009 3.3.2*

*Cereal processing tools assessed for improving bioavailability of iron and zinc in young childrens' diets*

A literature review on different cereal processing tools (decortication, fermentation, germination etc.) is being finalized. A new project, which is aimed to improve the iron and zinc status and to assess the acceptability of germination practices for infant feeding in rural settings, is in the preparatory phase. The project will initially start in two villages in the zone of Mandé in Mali.

*Output Target 2010 3.3.1*

*Effectiveness of integrated management techniques, including new preferred varieties resistant to aflatoxin contamination, assessed and knowledge shared with associated capacity development with partners*

From the limited farmer participatory variety trials using *Aspergillus flavus* tolerant varieties, it is clear that these varieties will play a major role in controlling aflatoxin contamination of groundnuts. A larger set of new *Aspergillus flavus* tolerant varieties will be screened on station to identify those that will be tested on farm. Thus new breeding lines with tolerance to aflatoxin and drought will be evaluated with farmer participation. Scaling-up of the validated pre-and post harvest technologies is also being encouraged in other countries in West Africa

## **Project 4: Producing more and better food from staple cereals (sorghum and millets), and legumes (groundnuts, chickpea and pigeonpea) at lower cost in the ESA-SAT through genetic improvement**

Progress in achieving the 2007 output targets for Project 4 activities and towards delivering on the project outputs is outlined for each output.

**Output 4.1: Sustainable regional breeding networks that integrate conventional and biotechnology tools established and associated capacity building. The target is to improve and strengthen efficiency of breeding and cultivar evaluation for ICRISAT crops across the ESA region while conserving and making maximum use of the natural genetic resource base**

### **Summary**

*To facilitate the strategy of regionalized crop improvement and understand the tools and methods deployed in such strategic research, 34 sorghum and millet collaborators from 10 countries in ECA were trained on GIS and database techniques essential to pursue regionalized crop improvement. To implement the strategy, regional trials were composed and distributed to collaborators. The Regional Sorghum Hybrid Trial was evaluated at Kiboko, mainly with white grain (representing the DL) and Alupe (SH), with brown colored grains, during 2006/07 and 2007 cropping seasons, respectively. Trial sets were also sent to Tanzania (Naliendele) and Malawi. Consistency in good performance of hybrids IESH 22002, IESH 22019, IESH 22011, IESH 22010 and SDSH 409 were observed across the two seasons and locations. The best yielding hybrids at Alupe were SDSH 409, SDSH 90003 and IESH 22021 with yields ranging from 3.420 to 3.878 t ha<sup>-1</sup>. Highland sorghum improvement has been initiated and evaluation of highland materials in high altitude Karatu Tanzania indicated that cold tolerant varieties originating from Rwanda (BM 5, IS 25570, BM 21, S 79, Urukara, BM 27 and Ikinyaruka) had grain yields ranging from 2.056 to 2.500 t ha<sup>-1</sup> compared to the local check with yields of 0.889 t ha<sup>-1</sup>. More sites will be included in the 2008 highland sorghum evaluation.*

*A pearl millet cultivar improvement team has been constituted and a regional pearl millet trial with 16 entries was planted in Kenya (Kiboko and Kambi ya Mawe), Tanzania (Hombolo) and South Africa (Potchefstroom). Varieties Okashana 1, ICMV 91450, Shibe, KAT PM 1, ICMV 96603 and SDMV 93032 (Okashana 2) attained grain yields between 2.066-2.713 t ha<sup>-1</sup> across the 4 test sites. Okashana 1 was the best variety across sites. A test crosses evaluation of top cross pearl millet was also initiated, targeting the same countries and there are plans to diversify the pollen source varieties/populations.*

*Newly developed medium-duration (photoperiod and warm temperature insensitive) pigeonpea cultivars targeting southern Africa were evaluated at Chitedze Research Station. Six varieties with grain yields ranging from 2.00 to 2.64 t ha<sup>-1</sup> that matured within 170 days, were identified. The varieties were cream seeded with acceptable grain size. Five of these varieties (ICEAP 01514/15, ICEAP 01480/32, ICEAP 01162/21, ICEAP 01167/11 and ICEAP 00557) have now been identified for on-farm testing during the 2007/2008 cropping season in central Malawi and Mozambique. In preparation for genetic transformation, 7 varieties of pigeonpea and 6 varieties of groundnuts that are popular in the ESA region were tested for regeneration response in tissue culture and initial results are promising. The protocol used for each crop is being optimized.*

*Introduction of grain legumes, such as chickpeas, in a cereal based farming system, can help alleviate the problems associated with low productivity due to poor soil fertility, food and nutritional insecurity and result in increased incomes through sale of surplus production. Preliminary observations confirmed excellent growth of chickpea cultivation in a monomodal rainfall pattern after tobacco or rice. The most promising varieties, ICCV 95311, ICCV 97306 and ICCV 92318, will be evaluated on-farm in subsequent seasons and promising materials will be multiplied through the USEBA program currently operational in Mozambique.*

*2007 4.1.1 Regional sorghum hybrid trials with brown/red and white seeds evaluated in short/medium season environments in ESA*

Heterosis is an important component of the performance of sorghum hybrids. As a cultivar option, hybrid superiority is determined by their yield advantage over improved varieties than by their yield over their inbred parents. Development and evaluation of sorghum and millet hybrids targeted to Dry Lowland (DL) and Sub

Humid (SH) Lake Zone production systems is a continuous process. The main focus is to identify hybrids with adaptation to the specific agro ecological zones while meeting the end use quality traits of the farming communities. The process involves development of new hybrids as well as evaluation in targeted environments to determine adaptability and acceptability. A Regional Sorghum Hybrid Trial was composed, mainly with white grains, and evaluated at Kiboko (representing the DL) and Alupe (SH) -with brown grains- during the 2006/07 short rain and 2007 long rain cropping seasons respectively. Trial sets were also sent to Tanzania (Naliendele) and Malawi in 2007. The consistency in good performance of hybrids IESH 22002, IESH 22019, IESH 22011, IESH 22010 and SDSH 409 was observed across the two seasons and locations. At Kiboko in 2006 LR, these hybrids had grain yields ranging from 2.482 to 2.987 t ha<sup>-1</sup> (checks 0.992-1.319 t ha<sup>-1</sup>) whereas in 2006/7 (an exceptionally good year with rainfall amounting to 717.7 mm), the grain yields ranged from 7.740 – 9.240 t ha<sup>-1</sup> (checks 4.450 – 6.170 t ha<sup>-1</sup>). The best yielding hybrids at Alupe were SDSH 409, SDSH 90003 and IESH 22021 with yields ranging from 3.420 to 3.878 t ha<sup>-1</sup> (checks 2.487-3.036 t ha<sup>-1</sup>). However, SDSH 409 was more suited at Alupe due to its brown grain color and hence gets less mold. At Ukiriguru, the best hybrids, IESH 22002, IESH 22005, IESH 22006 and IESH 22009 (0.067 -2.489 t ha<sup>-1</sup>) were however out-yielded by the best variety Gadam el Hamam (2.556 t ha<sup>-1</sup>). Across seasons the performance of the hybrids in Kiboko in 2005 and two seasons for 2006, the best five hybrids were IESH 22019, IESH 22002, IESH22011, IESH 22010, IESH 22006 and all have white grains.

A preliminary sorghum hybrid trial comprising 19 new hybrids selected from the test cross evaluation of 2006 long rainy season was established at Kiboko during 2006/7 rainy season targeting the Dry Lowlands. All the hybrids had excellent seed set (96% and above) and nine hybrids attained yields above the trial mean grain yield (4.940 t ha<sup>-1</sup>) and have been selected to form the advanced hybrid trial for evaluation in 2007/8 cropping season. The hybrids were also evaluated for sweetness and the highest yielding hybrid (ICSA90001XICSR160) was also found to be very sweet together with three others. A restorer line ICSR 93001 was also very sweet and the two very sweet hybrids had ICSR 93001 as the male parent. These hybrids will be further evaluated for sweetness and yield in the ongoing efforts to identify sweet sorghum for bioethanol production.

Two seed companies (East African Seed Co. and Dryland Seed Ltd- Machakos) with interest in testing, targeting release and marketing of hybrid sorghums, were given some of the best performing hybrids for evaluation in Eastern Kenya particularly for grain production.

MA Mgonja, E O Manyasa, E Mwangi and J Kibuka

#### *2007 4.1.2: At least one multi-disciplinary pearl millet cultivar improvement team operational amongst regional NARS in ESA*

Pearl millet is a niche crop in the ESA region, grown in localized areas where normal rainfall does not permit reliable production of other dry land cereals such as sorghum and maize. The crop is distributed all over the region especially in the low altitude areas of Kenya and the central plateau of Tanzania. In southern Africa, these areas are primarily the fringes of the Kalahari Desert (Namibia, Botswana and North Western Zimbabwe), mid latitudes areas of low rainfall in Malawi and Mozambique, Zimbabwe, Angola and Namibia.

Approximately 27% of SADC's pearl millet area is accounted for by Namibia and Tanzania. The growing environments are characterized by low and erratic rainfall, high temperature, poor soil fertility and minimal external inputs. Pearl millet yields are usually much lower than those of other cereals (which are grown under more favorable conditions). Furthermore, yields are highly variable from one season to another. A regional pearl millet trial consisting of 16 entries originally tested in southern and eastern Africa was constituted and planted in Kenya (Kiboko and Kambi ya Mawe), Tanzania (Hombolo) and South Africa (Potchefstroom). Varieties Okashana 1, ICMV 91450, Shibe, KAT PM 1, ICMV 96603 and SDMV 93032 (Okashana 2) attained grain yields between 2.066-2.713 t ha<sup>-1</sup> across the 4 test sites. Okashana 1 with yields of 1.932 t ha<sup>-1</sup> (Kampi ya Mawe), 3.845 t ha<sup>-1</sup> (Kiboko), 3.224 t ha<sup>-1</sup> (Potchefstroom) and 1.85 t ha<sup>-1</sup> (Hombolo) was the best variety across sites. Relatively good rainfall was received at Potch (439.5mm), Kampi ya Mawe (386.8mm) and Kiboko (771.7mm) during the cropping season hence the good yields.

A test cross evaluation of 52 top cross hybrids developed at Kiboko using adapted A-lines from ICRISAT India and Okoa, Shibe, ICMV221, KAT PM 1, Okashana 1 and PMV 3 during the 2006/7 season was done. Only 12 hybrids attained seed set between 60-70%. The cross 253x254/KOGX Okoa had a high seed set of 80% and a 1.562 t ha<sup>-1</sup> grain yield. There is need to test more varieties/populations on the adapted A-lines to identify parents that combine well with acceptable fertility restoration and grain yields. There is increasing interest on testing hybrid pearl millet by Tanzania, Kenya, RSA and also Zimbabwe.

MA Mgonja, EO Manyasa and E Muange



*2007 4.1.3: Training NARS partners on use of GIS tools to delineate recommendation domains and mapping adaptation of improved varieties*

Sorghum and millets are important crops for the semi-arid tropics and they offer viable options in these harsh environments where other crops do poorly. Production and productivity is constrained by a number of biotic and abiotic stresses most of which cut across national borders. Technology generation, targeted and managed dissemination (scaling out and spillovers) require an efficient approach informed by a good understanding of agro ecological classification, production systems and biophysical factors as well as socio-economic conditions in terms of human and physical resources. GIS is a tool that uses spatial data to delineate recommendation domains as per input data. It is critical therefore that all collaborators in a regional program understand the production challenges to streamline research for development and to explore opportunities to make R&D more efficient and effective. A GIS training was organized by ICRISAT and ECARSAM and it covered aspects of theoretical knowledge and extensive guided practical sessions on introduction to principles of GIS and remote sensing (RS) and their application, preparation, analysis and modeling of adaptation domains for sorghum and millets. This was accomplished by step by step demonstration and guided hands on practicals using ArcGIS and IDRISI Kilimanjaro for GIS and RS, respectively, including GPS reference data capture. The course was attended by 34 participants, 8 of who were women. The participants were drawn from Kenya, Uganda, Tanzania, Ethiopia, Eritrea, Sudan, Rwanda, Burundi, DRC and Madagascar. The training achieved its objectives of imparting knowledge on principles of GIS, RS and participants capability to use GPS; methods of data capture and collection within a geo spatial context and practical application of geospatial technology to modeling of sorghum and millets. The participants were able to generate maps using various data inputs, including appreciation of key AEZs and production systems for sorghum and millets.

B Mitaru and MA Mgonja

*2007 4.1.4: Seven locally adapted pigeonpea and groundnut varieties in tissue culture*

Seven pigeonpea varieties that are cultivated in Africa were tested for regeneration response in tissue culture according to the method that is used routinely in India. The aim was to determine which varieties are most suitable for future genetic transformation. Included were two short duration varieties (ICPV 87091 and ICPV 86012), two medium duration varieties (ICPV 00554 and ICPV 00557) and three long duration varieties (ICPV 00020, ICPV 00040 and ICPV 00053). Regeneration of shoots from single cells was accomplished for all seven varieties and the small number of rooted plants that were transferred to a greenhouse were phenotypically normal and set viable seed.

Six groundnut varieties (ICGV 2, ICGV 12991, ICGV-SM 99568, ICGV-SM 90704, JL24 and Chalimbana) that are cultivated in eastern and southern Africa were used for tissue culture from cotyledonary explants according to the method that is routinely used in ICRISAT, India. In initial experiments, regeneration of shoots from single cells has been accomplished for all six varieties and rooted plants have also been obtained for all varieties. This protocol is being optimized for transformation purposes.

S de Villiers and D Hoisington

*2008 4.1.1: A regional highland sorghum improvement program initiated with at least two NARS in ESA*

Sorghums occupy a unique ecological niche in highlands and they require some level of cold tolerance especially to maintain viability of the pollen because flowering coincides with onset of the cool season. In Eastern Africa, highland sorghums are grown in the Rift Valley of Kenya, northern zone of Tanzania, Ethiopia, Eritrea, Rwanda, Burundi and south western Uganda. Breeding and selection of sorghums for highlands has been left to each national program. However there is merit in pursuing a regional highland crop improvement program that will facilitate sharing of materials and information for this specific breeding target.

One set of a cold tolerant trials was constituted with 48 entries and sent to Karatu Tanzania in January 2007 for evaluation by Bjarne Lausten of Network for Ecological Education and Practice-Sustainable energy project. The cold tolerant varieties originating from Rwanda (BM 5, IS 25570, BM 21, S 79, Urukaraza, BM 27 and Ikinyaruka) had grain yields ranging from 2.056 to 2.500 t ha<sup>-1</sup> compared to the local check with yields of 0.889 t ha<sup>-1</sup>. The mean days to 50% flowering was 86 days, however, the high yielding lines flowered in about 83 to 85 days and also attained a plant height of more than 2.10 m and a mean seed set of 89%. The trial will be repeated in 2008 at more locations in Karatu region and in Kenya. There are plans to collect highland sorghums from Tanzania and any other country and conduct characterization/evaluation trials to determine adaptability to cold temperatures.

*2008 4.1.3: Introduction of chickpea into monomodal rainfall regimes in southern Africa*

A major limitation to crop productivity in the monomodal rainfall areas of southern Africa is the lack of nitrogen. At the same time rural populations are food and nutritionally insecure. The introduction of grain legumes such as chickpeas can help alleviate both problems, and at the same time increase incomes through sale of surplus production.

Improved *Desi* and *Kabuli* chickpea varieties from ICRISAT-Patancheru have been evaluated in the monomodal rainfall areas of Malawi and Mozambique. Chickpeas have been relay-planted into tobacco and after-flooded rice. To improve chickpea productivity and enhance biological nitrogen fixation, an experiment was conducted to evaluate the effect of rhizobium inoculation with different rhizobium strains. Preliminary observations confirmed the excellent growth of chickpea in both systems, but quantitative results are not yet available. Seed production of the three most promising varieties ICCV 95311, ICCV 97306 and ICCV 92318 has been undertaken so that on-farm research can be initiated in subsequent seasons.

*Development of source seed supply models to facilitate access to publicly-developed varieties:* The lack of availability of source seed of improved publicly-developed varieties has been identified as a major constraint to the adoption of improved seed by smallholder farmers. ICRISAT in partnership with IIAM has developed an innovative institutional arrangement to address this constraint in Mozambique. A document has been prepared detailing the roles and responsibilities for an autonomous foundation seed enterprise, and the relationship between this institution and IIAM which is the primary organization developing improved varieties in Mozambique. Pilot seed production using contract growers has been undertaken and source seed supplied to local seed companies and other institutions working with smallholder farmers.

RB Jones, C Dominguez and W Leornado

*2009 4.1.1: At least 3 high-yielding medium-duration pigeonpea cultivars adapted to the ecological and cropping systems in southern Africa developed and available with associated capacity development to NARS*

Photoperiod and temperature sensitivity in both medium- and long-duration pigeonpea were two of the limitations for increasing productivity of pigeonpea particularly for medium-duration in high-latitude (10° to 20° north and south) areas in ESA. In such areas, flowering and maturity are delayed by long days and warm temperatures thus rendering the crop prone to terminal drought stress and winter frost. Newly developed medium-duration (photoperiod and warm temperature insensitive) cultivars developed for southern Africa were evaluated at Chitedze Agricultural Research Station (13°59' S and 33°44' E,) Malawi during the 2006/07 cropping season. Several traits were used for evaluation and selection and included the number of days to 50% flowering (50%DF), number of days to 75% maturity (75%DM), grain size (100-GW) and grain yield. Results showed that the varieties tested would escape terminal drought and frost and are all high yielding, ranging from 1.16 to 2.64 t ha<sup>-1</sup>. There were 6 varieties whose grain yield varied from 2.00 to 2.64 t ha<sup>-1</sup> and matured within 170 days. The varieties were cream seeded with acceptable grain size, both traits preferred by end users. Seed of these top yielding varieties will be increased. During 2005/2006 cropping season, seven varieties were identified and seed multiplied in 2007. Five of these varieties (ICEAP 01514/15, ICEAP 01480/32, ICEAP 01162/21, ICEAP 01167/11 and ICEAP 00557) have now been identified for on-farm testing during the 2007/2008 cropping season in central Malawi and in Mozambique.

SN Silim, M Somo, D Ojwang and P Kaloki

**Output 4.2: Improved germplasm and parental lines of adaptable sorghum, pearl millet, finger millet, pigeonpea, chickpea and groundnut that are resistant to chronic biotic stresses and meet end user preferences developed and disseminated with new knowledge to partners**

**Summary**

*Striga and midge are among the most serious biotic stresses of sorghum in many parts of SSA. Molecular markers tightly linked to Striga resistance Quantitative Trait Loci (QTL) have been identified and are being used in Marker Assisted Selection (MAS) integrated with farmer-participatory selection to move Striga resistance from resistant donor (N13) to susceptible Farmer Preferred Sorghum Varieties (FPSV) from Eritrea, Kenya and Sudan. Breeding for resistance to sorghum midge was initiated in year 2000 and selection of progenies derived from crosses between midge resistant (MR) sources from India and IS 8613, IS 21016, and*

AF 28 were evaluated in Kenya under natural midge infestation. Out of 155 lines, 54 have been advanced to preliminary evaluations. In addition, 80 elite sorghum lines developed between 1994 and 1996 were evaluated for midge tolerance and 22 lines had low midge damage scores  $\leq 3.0$  and grain yield potential of  $> 2.0 \text{ t ha}^{-1}$ . A Moi University student is conducting a project to map midge resistance QTL in order to identify SSR markers closely linked to these QTLs and to initiate the development of sorghum varieties with resistance to sorghum midge through MAS. The student is developing segregating populations between a highly midge resistant sorghum landrace AF28 with a susceptible cultivar Seredo. Seeds of F5 will be genotyped for mapping of midge resistant QTL.

Pearl millet downy mildew, caused by the pathogen *Sclerospora graminicola*, is one of the diseases causing huge losses on farmers' fields in SSA. Introgression of downy mildew resistance into farmers preferred pearl millet varieties and associated capacity building on MAS is being pursued by the Lake Chad Research Institute in collaboration with BecA. The confirmed hybrids, are being backcrossed to their respective recurrent parent to develop BC<sub>1</sub>F<sub>1</sub>s.

Newly developed medium-duration (photoperiod insensitive) pigeonpea cultivars developed for southern Africa were evaluated at Chitedze Malawi. The cultivar ICEAP 01480/32 had the highest grain yield ( $3.0 \text{ t ha}^{-1}$ ) followed by ICEAP 01514/15 ( $2.9 \text{ t/ha}$ ) compared to a local variety Royes ( $1.0 \text{ t ha}^{-1}$ ). Evaluation of determinate short duration pigeonpea was done at Kiboko. The genotype ICEAP 01275 obtained the highest yield ( $1.97 \text{ t ha}^{-1}$ ) which was 25% more than the yield of the check variety ICPL 90050 in Ilonga Tanzania. The variety ICEAP 00624 had the highest yield ( $1.24 \text{ t ha}^{-1}$ ) and attained 50% flowering in 57 days. Seed of elite pigeonpea cultivars was disseminated to partners in the region particularly in Tanzania (Babati, Karatu, Mbulu districts and the Lake Zone) as well Makueni in Kenya. One of the major drawbacks in the short-duration germplasm is its susceptibility to insect pests particularly pod borers and pod suckers. Crosses have been made between large seeded medium- and long-duration varieties with the released short-duration variety, ICPL 87091 and a number of short-duration lines are available for evaluation.

Groundnut germplasm with disease resistance, adaptation, farmer and market preferred traits have been developed and evaluations resulted in identification of potential sources of rosette resistance from a medium duration line ICGV-SM01731 and 3 additional sources from the mini-core collection. The infector row technique, in combination with screening in hot spot areas and shuttle breeding are currently being used in eastern and southern Africa to enhance screening for GRD resistance. There are excellent progenies in the nurseries that combine ELS and rosette resistance. A groundnut working collection of 12 farmer- and market-preferred varieties has been identified and will be crossed with 2 rosette virus resistant, 1 aphid resistant, 2 ELS and 3 rust resistant materials as the basis of a marker-assisted breeding program to identify combined disease resistance.

The availability of information on improved varieties and how they perform needed to help seed companies and farmers make informed decisions about which varieties to commercialize is limited because national variety catalogs are poorly maintained, and where they exist contain little information. A web-based catalog template that could be used both as a national catalog, and to support the implementation of regional variety release agreements have been developed and a first round of training regional information staff has been accomplished. Training of trainers, building the capacity of stakeholders and linking farmers to markets are catalysts for sustainable demand and seed supply. The trainers were trained on groundnut crop husbandry, agribusiness and group dynamics. This was linked to bulking and dissemination of over 100 Mt seed of improved ICRISAT groundnut varieties in Kenya and Malawi. Similarly about 760 kg of seed of the sorghum variety IS8193 were distributed to 1560 farmers in Teso, Busia, Siaya and Homabay districts through the Lucrative Legume Project that was distributing groundnut seeds.

New issues, demands and opportunities are likely to emerge based on better understanding of how to address global socio-economic and environmental challenges. Issues related to health and nutrition are becoming important components of food security, whereas concerns about climate change, energy and environmental safety are in the mainstream of global concerns. On energy, the dual-purpose nature of sweet sorghum, producing both grain and sugar-rich stalk offers new market opportunities for smallholder farmers' integration in production of bioethanol as an alternative to fossil fuel. Identification of adaptable sweet sorghum cultivars that can be used in pilot programs to optimize production of bioethanol under diverse production environments is in progress. Potential varieties/lines such as SPV 422 and IS 2331 which also had grain yields of  $3.5$  and  $4.0 \text{ t ha}^{-1}$  respectively, and a number of hybrids such as ICSA102XE36-1 and ICSA285 X SSV74 with brix levels of 15.8% and 15.4% respectively and grain yields of up to  $3.7 \text{ t ha}^{-1}$  have been identified. These are currently

under evaluation in multiple environments and with partners collaborating in envisaged pilot programs for commercial viability of sweet sorghum-based bi-ethanol production in eastern and southern Africa.

Demand for livestock products (mainly milk and meat) in SSA is expected to double by 2020 and this requires increased availability of feed and fodder for livestock. Sorghum has the potential to meet most of this demand especially in the SAT. Local and improved varieties with varying end users attributes, eg., food, feed, forage and fodder were identified. The Eastern Kenya local varieties (Mugana, Muthiriku and Nguugu) had highest fresh and dry biomass yields. The lines developed in southern Africa had above average grain yields but performed poorly in forage yield except the line SDSL90162-1 which had high biomass yield ( $30.5 \text{ t ha}^{-1}$ ) and also high grain yield of  $3.1 \text{ t ha}^{-1}$ . The lines from India did not perform as well as the locally developed lines in terms of forage and grain yield. There are opportunities to use the local varieties and ESA bred materials in breeding to improve dual purpose sorghum for grain and forage yields.

To address the concerns of nutrition, finger millet grain is superior to other staple cereals and is particularly rich in methionine, iron and calcium. Currently, finger millet varieties are being evaluated for blast resistance and a number of lines have been identified with good yield potentials such as KNE 688 ( $1.429 \text{ t ha}^{-1}$ ), KNE 689 ( $1.231 \text{ t ha}^{-1}$ ), KNE 1034 ( $1.164 \text{ t ha}^{-1}$ ), Acc.# 29 FMB/01 WK ( $1.457 \text{ t ha}^{-1}$ ), Acc # 32 FMB/01 WK ( $1.164 \text{ t ha}^{-1}$ ) and Acc. # 14 FMB/01 WK. However, the most blast resistant/tolerant lines were P224, KNE#814, KNE# 622, and KNE#434 with overall blast score of less than 2 on a 1-9 scale and these have been included in finger millet regional trials, on farm evaluation and promotion. The objective is to improve finger millet productivity to meet the growing food and nutrition security as well as market demands.

#### **2007 4.2.1: SSR derived markers more tightly linked to *Striga* resistance in sorghum identified and mapped**

Significant progress has been made in identifying molecular markers for *Striga* resistance in sorghum under field conditions by ICRISAT over the last 10 years. Five genomic regions (quantitative trait loci, QTL) associated with stable *Striga* resistance from resistant line N13 have been identified across a range of 10 field trials in Mali and Kenya, and two independent samples of a mapping population involving this resistance source. Flanking microsatellite or Simple Sequence Repeat (SSR) markers to the QTL are available for use in marker-assisted selection (MAS). MAS studies have, amongst others, revealed that the tighter molecular markers are linked to target QTL, the more efficient the MAS procedure tends to be. The five QTL for *Striga* resistance on sorghum LGs 1, 2, 5 and 6, are positioned on genomic intervals flanked by SSR markers, ranging in size from 13 to 56 cM. These intervals correspond to approximately 5.7 to 24.5 Mb, using a total sorghum genetic map length of 1713 cM (Menz et al. 2002) and a sorghum genome size of 750 Mb (Arumaganathan & Earle 1991). The average gene content of 76 ORFs/Mb, implies that with the transfer of *Striga* QTL from N13 to the FPSVs, many additional genes with possible negative effects on the phenotypes will be unintentionally transferred. MAS using markers more tightly linked to the *Striga* resistance QTL will reduce the impact of linkage drag and thereby increase chances of farmer adoption of the FPSVs enriched with *Striga* resistance. The main objective of this project is to utilize molecular markers tightly linked to *Striga* resistance Quantitative Trait Loci (QTL) in marker-assisted selection (MAS) and farmer-participatory selection in order to move *Striga* resistance from resistant donor (N13) to susceptible Farmer Preferred Sorghum Varieties (FPSV) from Eritrea, Kenya and Sudan. The project builds upon the products, BC<sub>2</sub>S<sub>2</sub> lines, generated through the BMZ project entitled “Arresting the scourge of *Striga* on sorghum in Africa by combining the strengths of marker-assisted backcrossing and farmer-participatory selection”. Four BC<sub>2</sub>S<sub>2</sub> lines with 3 and 4 *Striga* resistance QTLs were provided to Nairobi University (Kenya) and they have been backcrossed to the local variety Ochuti to generate BC<sub>3</sub>F<sub>1</sub>. In Sudan, several lines with 1, 2 and 3 QTLs have been backcrossed to the local varieties Tabat and BC<sub>3</sub>F<sub>1</sub> seeds generated. Progress has been made but the output has not been fully met since ASARECA, the donor, froze all project activities from June 2007. In addition, we are collaborators and have no project coordination responsibilities. We have done our part of training and providing *Striga* resistant BC<sub>2</sub>S<sub>2</sub> lines.

D Kiambi, T Hash and D Hoisington

#### **2007 4.2.2: Markers segregating with traits associated with resistance to sorghum midge identified and linkage map of the F<sub>2</sub> population derived from AF28 and Seredo generated**

The three most destructive insect pests of sorghum in the ASARECA (Association for Strengthening Agricultural Research in East and Central Africa) region are the sorghum midge (*Stenodiplosis sorghicola* Coquillet), spotted stem borer (*Chilo partellus* Swinhoe) and sorghum shoot fly (*Atherigona soccata* Rond.) Therefore, one of the research priorities in ECARSAM (the Eastern and Central Africa Regional Sorghum and

Millet Network), the sorghum and millet network of ASARECA is midge control in sorghum. The identification of sorghum genotypes with stable resistance to sorghum midge is hampered by genotype  $\times$  environment interactions since midge resistance in sorghum is location specific. It is envisaged that identifying DNA markers closely linked to midge resistance loci and using these markers in marker-assisted selection (MAS) will aid breeding for sorghum midge resistance. The project therefore aims to identify SSR markers closely linked to midge resistance QTL and to initiate the development of sorghum varieties with resistance to sorghum midge through MAS. In order to achieve this, a cross was made between AF28 (highly resistant, locally adapted sorghum landrace and Seredo (a high-yielding, drought tolerant, midge susceptible Kenyan sorghum cultivar). The F<sub>1</sub>'s were genotyped in the ICRISAT/ BecA lab using SSR markers to confirm whether they were true hybrids. The F<sub>2</sub>, F<sub>3</sub>, F<sub>4</sub> and F<sub>5</sub> populations have been generated in Alupe, Kenya under severe midge natural infestation. Seeds of F<sub>5</sub> inbred lines are now available for genotyping and mapping of QTL. Progress has been made towards meeting the output target but it has not been fully met as the work was being done by a PhD student who had to abandon the research activities in order to finish course work.

We are collaborators in the project and have project coordination or formal supervisory responsibility for the PhD student.

D Kiambi and D Hoisington

*2007 4.2.3: Sorghum and millet improved lines with resistance to midge, stem borer and leaf disease evaluated in advanced trials for yield and adaptability*

Sorghum midge [*Stenodiplosis sorghicola*] is the most widely distributed of all sorghum insect pests followed by stem borers (*Chilo partellus* and *Busseola fusca*-) and shoot fly (*Atherigona soccata*). Of the leaf diseases, the most prevalent is Anthracnose caused by *Colletotrichum graminicola* and leaf blight (*Exserohilum*-). Host plant resistance and time of planting are some of the important components for the integrated management of the pest. Several sources of resistance to midge have been identified, however the levels of resistance vary from one location to another. This calls for localized breeding and testing for sorghum to midge resistance. In the 2006 long rain season, a total of 155 lines derived from crosses between midge resistant (MR) sources from India and IS 8613, IS 21016, and AF 28 were evaluated in a preliminary trial at Alupe, Kenya. A total of 54 lines were advanced in 2007 long rainy season at Alupe under natural infestation. Nine lines, all from cross MR # 22 X IS 8613 had the best resistance to midge (midge damage scores  $\leq$  4.0), disease (scores  $\leq$  3.0) and with good grain yield potential ( $>$  2.0 t ha<sup>-1</sup>). One of the lines from the cross MR # 22 X IS 8613 had a high disease score of 6.7, a midge score of 2.3 (on 1-9 scale) and a yield of 3.065 t ha<sup>-1</sup> whereas another line from the same cross had a midge score of 6.7 and a disease score of 4.0 but the grain yields was 1.435 t ha<sup>-1</sup>. During the 2006 season late planting, the cross MR # 7 x AF 28-2-5-1-1-1 which showed the best performance against midge with a score of 4.0, had in 2007 a midge score of 2.2 and a high disease score of 6.7 but had high grain yield of 2.866 t ha<sup>-1</sup>. These findings call for analyses of relative importance of diseases and midge in the Lake Zone area and also offer opportunities for enhancing both midge and disease resistance. During the season, 80 elite sorghum lines developed between 1994 and 1996 were evaluated for midge tolerance. Twenty-two lines had midge damage scores  $\leq$  3.0 with grain yield potential of  $>$  2.0 t ha<sup>-1</sup>. In both trials, the local check varieties, IS 8193 and Seredo had midge damage scores  $\geq$  4.0. The midge resistant lines will be included in regional trials for further evaluation across environments where sorghum is prone to midge infestation.

MA Mgonja, E Manyasa and J Kibuka

*2007 4.2.4: At least one new source of resistance to rosette, ELS, Rust and/or aflatoxin contamination identified in germplasm annually from 2007 to 2011*

Repeated trials from the past three seasons have revealed potential source of rosette resistance from a medium-duration line, ICGV-SM 01731. Three more sources of resistance to rosette have been identified in the mini-core collections from India. These are ICG 6888, ICG 13099 and ICG 14705 and await further confirmation in the greenhouse. Efforts to find new sources of resistance to early leaf spot seems to pay off from results obtained from mini-core collections planted under high ELS disease pressure. One line ICG 6022 (2) was identified and has been earmarked for further evaluation in the forthcoming 2007/08 season to confirm its resistance to ELS. Screening for rust resistance was hampered due to low rust disease pressure for the past three seasons. Elite aflatoxin resistant lines from ICRISAT Hyderabad were evaluated at an aflatoxin sick plot and results from the aflatoxin laboratory are being analyzed. Similar work will be done during the 07/08 growing season to evaluate sixteen new materials that have been sent from ICRISAT India with resistance to aflatoxin contamination.

ES Monyo, M Osiru and H Charlie

*2007 4.2.6: Improved sorghum varieties with adaptation, yield and grain quality characteristics desired by the end users tested in elite and advanced trials*

Forty-five advanced and 46 preliminary sorghum lines originating from crosses between bold grain B lines from ICRISAT- Bulawayo and adapted local and improved varieties to improve grain size, and grain yield were assembled. The lines were evaluated at Alupe in the long rainy season of 2006. Yields of the 11 best test lines in the advanced trial ranged from 2.292 to 2.736 t ha<sup>-1</sup> with 100 seed mass >2.9gm. The best check variety (IESV 93036 SH) yielded 2.222 t ha<sup>-1</sup>. In the preliminary yield trial, yields of the best 8 test lines ranged from 1.896 to 2.469 t ha<sup>-1</sup> and were above the best check variety IESV 93036 SH (1.854 t ha<sup>-1</sup>). The best lines were evaluated in Alupe in the 2007 long rain season in the Advanced Sorghum Variety (ASV) yield trial and the Elite Sorghum Variety (ESV) trial and each trial had 40 entries. From the ESV trials in Alupe in 2007, fourteen lines (grain yield range 4.102-5.301 t ha<sup>-1</sup>; checks 3.037-4.400 t ha<sup>-1</sup>) were selected and 11 out of the 14 lines had 100 grain weights above 3.4 g and about 10 lines with a disease score of less than 3 in a 1-9 scale. From the ASV trial, 19 lines (grain yield range 3.374-5.216 t ha<sup>-1</sup>; checks 3.235-4.807 t ha<sup>-1</sup>) with large grain (100 seed weight greater than 3.4 g) and leaf diseases tolerance were selected for further evaluation across more sites around the Lake Victoria Zone (Kenya, Uganda and Tanzania)

MA Mgonja, E Manyasa and J Kibuka

*2008 4.2.3 Training of trainers for local seed production techniques for improved groundnuts completed*

Seed availability and accessibility greatly limit groundnut productivity. A sustainable seed supply system of high yielding improved groundnut varieties tolerant to diseases, building the capacity of stakeholders and linking farmers to markets are catalysts for sustainable demand and seed supply. The Lucrative Legumes Project (LLP) has disseminated over 100 Mt of seed of improved ICRISAT groundnut varieties (ICG 12991, ICG 12988, ICG 2, ICG SM 99568, CG7, ICG SM 90704) to over 8,000 farmers (63% women) in western Kenya who are members of farmer producer groups. The farmers have been trained on good husbandry practices by 431 trained trainers (80% men) comprising 131 agricultural extension staff and 300 farmer leaders. The trainers were trained on groundnut crop husbandry, agribusiness and group dynamics. The farmers successfully bulked and supplied to group members and others outside their groups. Seventy-seven (77) of the farmers successfully grew groundnut seed for a local commercial seed company under contractual arrangement. The productivity of the improved ICRISAT varieties is over 3 times higher (1000 kg/ha) than traditional local varieties (350 kg/ha). Additionally, ICRISAT-Malawi staff trained 24 people (38% women) comprising scientists, seed farmer leaders and extension staff on groundnut seed production, disease diagnosis and management. Eleven postgraduate students (5 female, 6 male) have conducted research on factors that influence groundnut productivity, quality and marketing. The project is developing a groundnut production manual (in both electronic and paper version) suitable for college students and extension staff.

MW Mburu and RB Jones

*2008 4.2.4: Infector row technique for screening of GRD resistance established and operational with at least one NARS in ESA by 2008*

The infector row technique is currently being used in Eastern and Southern Africa at the ICRISAT Chitedze Research Centre with Malawi NARS. Efforts to use this technique in Tanzania during the 2006/07 were hampered by lack of a greenhouse.

At Chitedze, sixteen rosette disease nurseries (F5 – F7 generations) were established under high disease pressure. The rosette disease pressure was very good resulting in over 90% infection in the spreader rows and susceptible checks. Observed resistant progenies were to a great extent reflective of genetic resistance in the populations. From the 16 F5 – F6 nurseries, a total of 242 plants were identified for generation advance through single plant selection representation. Out of these we identified 73 single plant selections from 7 of the nurseries with 0% rosette incidence (18% of the progenies) and an additional 68 plants with rosette incidence ranging from 1 - ≤ 20%. From among 239 F7 progeny rows, 163 lines were identified for promotion to check-row yield performance trials (68%).

Six ELS nurseries ranging from F4 – F7 comprising 591 progeny rows were evaluated at Chitedze Research Station in Malawi for the purpose of identifying superior plants segregating for ELS resistance. There are excellent progenies in the nurseries that combined ELS and rosette resistance. Good progress is also being realized from utilization of the ELS hot spot screening nursery in Malawi to identify ELS resistant progenies

from segregating populations sourced from Hyderabad India. Shuttle breeding between the two programs hastens the rate of genetic advance. Hot spot screening nurseries helps breeders from both programs identify useful materials for particular constraints that would otherwise not have been noticed. Out of 79 progenies in F<sub>4</sub> selected from an initial nursery of 443 we have identified 33 with very good levels of resistance to ELS for promotion to F<sub>5</sub>. In pyramiding ELS resistance genes, 186 superior progenies combining ELS resistance from various sources have been selected for generation advance from this seasons' nursery of 240 F<sub>5</sub> progeny rows. Further progress has been achieved in selection of 37 single plants for generation advance from 49 progeny rows (in F<sub>5</sub> nursery) combining ELS resistance and confectionary market traits-essentially ELS resistance in large seeded germplasm.

There were two segregating population nurseries for rust and late leaf spot:

From 81 F<sub>7</sub> Rust and Late Leaf Spot resistance screening nursery, 81 families were selected to make one set of check row trial.

From two sets of check row trials each comprising 204 entries, 66 lines were identified to develop two sets of preliminary rust and rosette resistance trial, each consisting of 33 entries plus controls (36 entry trials). The rust and late leaf spot disease pressure was observed on few areas of the nursery hence selection for advance was mainly based on yield.

ES Monyo, M Osiru and H Charlie

#### ***2008 4.2.5: Web-based seed catalog to support implementation of regional variety registration***

The availability of information on improved varieties and how they perform helps seed companies and farmers make informed decisions about which varieties to commercialize. National variety catalogs are poorly maintained, and where they exist contain little information. The objective of this work is to develop a web-based catalog template that could be used both as a national catalog, and to support the implementation of regional variety release agreements.

A database was developed to contain all the distinctness-uniformity-stability (DUS) and Value for Cultivation and Use (VCU) information required by national release committees. The crops included are those that have been selected for the regional variety release systems in the Southern Africa Development Community (SADC), in the Association for Strengthening Agricultural Research in Eastern and Southern Africa (ASARECA), and in the Economic Community of West African States (ECOWAS). The web-based catalog and a first round of training of regional information technology staff from each of the regional economic communities was completed. A second round of training and the population of the database is expected to start in early 2008. A variety comparison tool provided gratis by Argentina has been built into the catalog so as to be able to compare varieties and avoid duplication of entries and protect the intellectual property of existing varieties. There is a strong interest from national regulatory authorities to utilize the same tool to maintain national variety lists. The web-based catalog has been developed by the International Livestock Research Institute (ILRI) with support from ICRISAT and the Seed Science Center, Iowa State University, USA.

Richard Jones

#### ***2008 4.2.6: Seed production and distribution system to enhance adoption of improved sorghum and finger millet varieties***

Adoption of improved sorghum cultivars by farming communities is often constrained by unavailability of seed and information on the performance of the varieties. Public and private sectors have dynamic roles to play in the seed supply system. Other areas for public intervention include capacity building of farmers through strategies such as demonstrations and availing seed to create future demand of the same after farmers' appreciation of the productivity enhancement from the quality seed of improved varieties. However different models can be efficient in different scenarios. In Kenya, we linked with the Lucrative Legume Project to increase seed of sorghum and finger millet. At the ICRISAT Alupe station, 6 hectares were planted with 6 finger millet varieties KNE814, Acc19, Acc14, Acc32, KNE629, U15, KNE1149, KNE688 and P224 and a total of 1.3 t of finger millet seed was harvested. The above finger millet varieties have been tested on farm in Teso, Busia, Kisii and Gucha districts. Similarly about 760kgs of seed of the sorghum variety IS8193 were distributed to 1560 farmers in Teso, Busia, Siaya and Homabay districts through the Lucrative Legume Project that was distributing groundnuts seeds. Some seed was given to three seed companies –Faida, Leldet and Kenya Seed for possible commercialization of the same. Some seed was given to Moi University in Kenya for screening against aluminium toxicity.

MA Mgonja, EO Manyasa and J Kibuka

2009 4.2.1: At least 6 newly improved pigeonpea cultivars for production in ESA evaluated, disseminated and promoted through participatory on-farm methods

Seed of elite pigeonpea cultivars was disseminated to partners in the region. In Tanzania, seed was disseminated to new pigeonpea areas (Babati, Karatu and Mbulu districts) and the Lake Zone. Our partners (Diocese of Mbulu-CRS and the Selian Agricultural Research Institute) facilitated this significant expansion of the area under pigeonpea in Tanzania. The wilt resistant long-duration cultivars (particularly ICEAP 00040 and ICEAP 00053) developed by ICRISAT were adopted widely in Babati and Karatu; and the medium-duration wilt resistant cultivars (ICEAP 00554, ICEAP 00557 and ICEAP 00068) are being grown by a large number of farmers in the Lake Zone of Tanzania. In Kenya, medium-duration cultivars, ICEAP 00554 and ICEAP 00557 are being grown in Makueni district and green pods sold in Nairobi and Mombasa where a premium is obtained. Seed production of released and/or pre-released varieties was done at Kabete and Kiboko in Kenya and a total of 3 t of breeder seed were harvested.

Some parts of ESA, such as eastern Kenya, experience a bi-modal rainfall pattern with the first season lasting only three months (November to January). Short-duration pigeonpea that mature within four months would escape drought and produce yields. ICRISAT had developed short-duration varieties that were released in Uganda, Kenya, Tanzania and Malawi, but farmers indicated that they took too long to cook and were small seeded. Crosses were made between large seeded medium- and long-duration varieties with the released short-duration variety, ICPL 87091 and a number of short-duration lines were obtained; these were evaluated in the 2006/2007 cropping season at Kiboko and Kampi ya Mawe. All the lines matured earlier or at the same time as ICPL 87091 and 59% had larger seed mass than the check variety. A nursery was constituted and given to the Tanzanian national program for evaluation during the 2007/2008 cropping season. One of the major drawbacks in the short-duration germplasm is its susceptibility to insect pests particularly pod borers and pod suckers. Currently, pesticides are necessary in the management of short-duration cultivars in ESA.

SN Silim, M Somo, D Ojwang and P Kaloki

2009 4.2.4: A groundnut working collection of at least 15 farmer- and market-preferred varieties, as the basis of a marker-assisted breeding program established by 2008

Consultation of available regional variety database coupled with information from partners' nurseries has identified the following candidate varieties for MAB. These will form the basis of the good x good crosses for the introgression of selected constraints into popular farmer/market preferred varieties.

The list below highlights farmer preferred popular varieties in the ESA and WCA regions, and the best elite germplasm sources of resistances to rosette, ELS and rust disease constraints.

|                                                                                 |                                                                                                                        |
|---------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Rosette virus resistant</b><br>ICGV-SM 90704<br>ICGV-IS 96894 Nigeria        | <b>Popular Varieties</b><br>Chalimbana - Malawi<br>Chalimbana 2005 - Malawi                                            |
| <b>Aphid Resistance</b><br>ICG 12991                                            | CG 7 - Malawi<br>JL 24 - Malawi                                                                                        |
| <b>ELS Resistance</b><br>ICGV-SM 95714<br>ICG 7878 ELS, LLS (Mali, large seed)  | ICGMS 33 (Pendo) - Tanzania<br>Johari (Robut-33) - Tanzania<br>Nyota (Spancros) - Tanzania                             |
| <b>Rust Resistance</b><br>ICGV 94114<br>ICG FDRS 4 - Mali<br>ICG FDRS 10 - Mali | Red Mwitunde - - Tanzania<br>55-437 Niger, Senegal<br>Fleur 11 Senegal, Mali<br>47-10 Mali<br>ICGV 86124 Mali, Senegal |

In addition to the above, field experimentation at the ICRISAT Chitedze Agricultural Research Station under high disease pressure for ELS and rosette, coupled with farmer participatory variety selection in both Malawi, Mozambique and Tanzania resulted in identification of the following elite varieties as good candidates for MAB.

Rosette resistance in early maturity background: ICGV-SM 99555, ICGV-SM 99557, ICGV-SM 99541, ICGV-SM 01514, ICGV-SM 01515, ICGV-SM 99529



Rosette resistance in confectionary large seeded background: ICGV-SM 01711, ICGV-SM 01731, ICGV-SM 01708

A hybridization program was initiated between known sources for resistance to rosette disease (ICGV-SM 90704, ICGV-SM 94584, ICGV-SM 01501) ELS; (ICGV-SM 93555, ICGV-SM 95714); and rust (ICGV-SM 94114 and ICGV-SM 95342) with the objective of producing F<sub>2</sub>/F<sub>3</sub> mapping populations and introgressing resistances to known farmer preferred adapted varieties in ESA region. All together 56 crosses were made during the winter season 2007. These will be planted during main season 2008 for generation advance.

ES Monyo, B Ntare and D Hoisington

*2009 4.2.5: Introgression of downy mildew resistance into farmer preferred pearl millet varieties and associated capacity building on MAS (2007)*

Farmers in SSA face substantial losses of pearl millet yield in their fields due to a range of diseases. Pearl millet downy mildew, caused by the pathogen *Sclerospora graminicola*, is one of the diseases causing huge losses on farmer's field in SSA due to the devastating nature of the disease. Three downy mildew resistant parents (PT732B-P2, P1449-2-P1 and P310-17B) were used to transfer downy mildew resistant QTL into six farmer preferred local varieties (LCIC 75B-3, LCIC DMR-15, ExBorno, Gwagwa, LCIC9702 and SOSAT-C88) in Nigeria. A pearl millet breeder at Lake Chad Research Institute in Nigeria (Dr Angarawai Ignatius) developed 644 F<sub>1</sub>s by crossing the 3 donor and 6 recurrent parents. Leaf materials from the 644 F<sub>1</sub>s plus the donor and recurrent parents were collected in 90% ethanol in September at Lake Chad Research Institute and brought to the BecA lab in Nairobi for molecular analysis. DNA was extracted from each sample and 24 foreground microsatellite markers were screened for polymorphism between the donor and recurrent parents. Three polymorphic foreground markers per cross were used to check whether the F<sub>1</sub>s are true hybrids. Confirmed true hybrids were then backcrossed with their respective recurrent parent to develop BC<sub>1</sub>F<sub>1</sub>s. Two days training was provided for 3 NARS breeders and 2 research technicians at Lake Chad Research Institute in Nigeria on DNA sampling protocols, including the right age for collecting leaf samples from breeding lines and sampling methods (FTA card, silica gel, acetone and ethanol).

K Semagn, I Angarawai, D Hoisington and CT Hash

*2009 4.2.6: Fast track selection of most promising sweet sorghum varieties and hybrids for further evaluation on farm and for industrial testing of ethanol production*

The dual-purpose nature of sweet sorghum, producing both grain yields of up to 2 to 2.5 t ha<sup>-1</sup> and sugar-rich stalk of about 40-50 t ha<sup>-1</sup>, offers new market opportunities for smallholder farmers. The pilot program for evaluating the commercial viability of sweet sorghum-based bioethanol production is a vital strategic investment for the region that would allow countries harness high payoffs by leveraging existing research results to develop a high value commercial product (biofuel). However, this needs to be preceded by identification of adaptable sweet sorghum cultivars that can be used in the pilot program to optimize production of bioethanol under diverse production environments.

Sweet sorghum research activities were started in November 2006 (the short rain season) and in April 2007 long rains season at Kiboko and Alupem respectively. At Kiboko, a nursery of 60 entries from various sources (locally bred materials, local germplasm, materials from ICRISAT Asia) was established and at maturity stalk sweetness was organoleptically tested. The mean biomass yield was 17.82 t ha<sup>-1</sup>. However, 24 lines had a biomass yield of more than 20 t ha<sup>-1</sup>. The lines had good grain yields (trial mean of 3.6 t ha<sup>-1</sup>). A total of 25 lines were selected based on their sweetness and also grain yield and these constituted an Advanced Sweet Sorghum replicated trial that was planted in 2007 April season in Kiboko and Alupe. At Kiboko, 11 lines recorded brix values between 14-16.4% and stripped stalk yield of 10.4 -17.1 t ha<sup>-1</sup>. At Alupe, 13 lines had brix values between 13 and 16.95% and stripped stalk yields between 5 and 24 t ha<sup>-1</sup>. These preliminary results at both locations have helped us to identify potential lines for further evaluation in multiple environments and with partners collaborating in the envisaged pilot program for commercial viability of sweet sorghum-based bioethanol production in East Africa.

MA Mgonja, EO Manyasa, J Kibuka and E Muange

*2008 4.2.7: Leveraging sweet sorghum materials from out of the region to identify varieties, hybrids and parents for further improvement, evaluation and adaptability testing*

Two International Sweet Sorghum trials from ICRISAT-India were also planted at Kiboko during the 2007 rainy season. The entries in the International Sweet Sorghum Trial (11 entries) had lower sugar levels relative to the local and improved regional lines. Brix levels above 13% were recorded in only two varieties SPV 422 and IS 2331 which also had grain yields of 3.5 and 4.0 t ha<sup>-1</sup> respectively. The variety NTJ2 had the lowest sugar content, and SPV1411 had the highest stripped stalk yield of 14.5 t ha<sup>-1</sup>. The International Sweet Sorghum Hybrids Trial (44 entries) had 12 entries having brix levels between 12-21%, however most of these hybrids were sterile. A total of 9 fertile hybrids (seed set above 86%) had brix levels between 11.3-15.8% and grain yields between 2.8 t ha<sup>-1</sup> and 5.0 t ha<sup>-1</sup>. The hybrids ICSA102 X E36-1 and ICSA285 X SSV74 had brix levels of 15.8% and 15.4%, respectively, and both had yields up to 3.7 t ha<sup>-1</sup>. Selections made from all the sweet sorghum variety trials have been constituted into an advanced sweet stalk sorghum trial that will be evaluated during the 2007/8 cropping season at Kiboko (Kenya), 4 sites in Mozambique and Alupe in the 2008 long rainy season. It should however be noted that at both locations (Kiboko and Alupe), brix readings were taken well after physiological maturity due to the late acquisition of the brix meter, hence the brix levels reported herein may be an underestimation of the materials' potential. Enough brix meters have now been acquired and next seasons' data will be taken at the appropriate time.

MA Mgonja, EO Manyasa and J Kibuka

*2009 4.2.7: Regional finger millet evaluated in at least two ESA countries to identify adaptable and blast resistance varieties for promotion and adoption*

The need to address issues of health and nutrition especially in the face of HIV/AIDS pandemic is increasingly becoming very important. Nutritionally, finger millet grain is superior to other staple cereals and is particularly rich in methionine, iron and calcium. Finger millet blast (*Pyricularia grisea* (teleomorph= *Magnaporthe grisea*) is the most serious disease of finger millet world wide. Scientists have characterized and assessed finger millet germplasm for blast resistance and some lines that have some degree of resistance to this disease have been identified. There is increasing need to evaluate these materials across the finger millet production areas and countries to make available to farmers some of the identified blast resistant materials to enhance productivity and meet the growing demands for food and nutrition security as well as market needs. A regional finger millet trial with 16 elite and blast tolerant/resistant lines was constituted and planted at Alupe in Kenya and sets sent to Malawi, Burundi and Eritrea. Results have indicated that KNE 688 (1.429 t ha<sup>-1</sup>), KNE 689 (1.231 t ha<sup>-1</sup>), KNE 1034 (1.164 t ha<sup>-1</sup>), Acc.# 29 FMB/01 WK (1.457 t ha<sup>-1</sup>), Acc # 32 FMB/01 WK (1.164 t ha<sup>-1</sup>) and Acc # 14 FMB/01 WK (1.058 t ha<sup>-1</sup>) as the best performing varieties with grain yields above 1.0 t ha<sup>-1</sup>. The most blast resistant/tolerant lines were P224, KNE 814, KNE 622 and KNE 434 with overall blast score of less than 2 on a 1-9 scale. Data from Burundi, Malawi and Eritrea are yet to be received.

MA Mgonja, EO Manyasa and J Kibuka

*2010 4.2.5: Diversifying sorghum end-uses to feed and fodder to enhance the livestock industry in eastern and central Africa*

Demand for livestock products (mainly milk and meat) in SSA is expected to double by 2020 and this requires increased availability of feed and fodder for livestock. Sorghum has the potential to meet most of this demand especially in the SAT. Being a C<sub>4</sub> crop, sorghum has tremendous potential for biomass production, most of which is accumulated in the vegetative parts. In most of Africa and in the semi-arid regions of Kenya, in which most of the livestock is raised, high productive dual-purpose types of sorghum, resistant to dry conditions are not in use. As grain (grits or bran), its use in poultry feed will complement other animal feeds to generate more income for producers/farmers and also enhance market opportunities for the crop. The objective of the study was to identify dual purpose sorghum varieties with grain, forage productivity and quality attributes that can be adapted to the semi arid drought prone lowland areas of Kenya.

Twenty five potential forage sorghum lines for dry lowlands were identified comprising 8 ICRISAT-Nairobi bred lines, 4 ICRISAT Bulawayo lines, 6 ICRISAT-India B-lines and 3 KARI lines, 2 lines (K 1593, B 35) and 2 or 3 local checks (Mugana, Muthiriku and Nguugu) cultivated in Embu/Mbeere/Meru in Eastern Kenya. The trial was established at three sites in Eastern Kenya (Kiboko, Kampi ya Mawe and Machanga) during the October/November 2006 season under rainfed conditions. Data were taken on forage traits like fresh biomass yield, dry biomass yield, and ear length and ear width. The other agronomic traits observed were grain yield, days to 50% flowering, plant height, number of leaves, number of tillers and stem diameter. The 2006/07 season was very favorable, and the combined grain yields of 3.76 t ha<sup>-1</sup>, 1.81 t ha<sup>-1</sup> and 2.80 t ha<sup>-1</sup> for Kiboko, KYM and Marimanti, respectively, were attained. The local varieties Mugana, Muthiriku and Nguugu had the highest fresh biomass yields of 42.1 t ha<sup>-1</sup>, 35.3 t ha<sup>-1</sup> and 39.4 t ha<sup>-1</sup> respectively and similarly the dry weights of 21.6 t

ha<sup>-1</sup>, 22.72 t ha<sup>-1</sup> and 19.25 t ha<sup>-1</sup> respectively but they had the lowest grain yields across the two sites. The ICRISAT Zimbabwe line SDSL90162-1 had high biomass yield (30.5 t ha<sup>-1</sup>) and also high grain yield of 3.1 t ha<sup>-1</sup>. The other lines which had biomass yields above the mean (19.9 t ha<sup>-1</sup>) and above the mean grain yield (2.8 t ha<sup>-1</sup>) included IESV92007, IESV92165DL, IESV99006DL, IESV99091DL, K1593, Kiboko Local and Makueni Local. The lines from India did not perform as well as the locally developed lines in terms of forage and grain yield, and all were below the trial means. The lines developed in southern Africa had above average grain yields but performed poorly in forage yield. The materials are currently being analyzed for chemical composition, in vitro digestibility and nutritive value for livestock. The evaluated local materials expressed high potentials for forage than for grain yield, whereas the ESA locally bred materials performed better in terms of forage and grain yield. There are opportunities to use the local materials and ESA bred materials in breeding to improve dual purpose sorghum for grain and forage yields.

MA Mgonja, B Mitaru, EO Manyasa and E Muange

**Output 4.3: New knowledge of the QTLs for the stay green and drought tolerance traits confirmed, and marker assisted selection efficiency improved, and specific abiotic stress tolerant varieties and associated knowledge for sorghum, pearl millet and groundnuts developed and disseminated in ESA with associated capacity development**

**Summary**

*Drought is considered to be the primary causes of yield reductions for crops in sub-Saharan Africa. Intra- and inter-seasonal variations in timing and intensity of rainfall result in drought stresses of various intensities and durations during crop growth. There are various approaches to address drought with one approach being the development of early maturing varieties that escape terminal drought. Stable F<sub>8</sub> progenies derived from crosses between Mahube (a very early variety) and improved dry lowland lines were constituted into a preliminary drought tolerant sorghum variety trial and evaluated in Kiboko. Out of 22 lines tested, 13 attained grain yields between 3.69-5.470 t ha<sup>-1</sup>. Selections have been made and used to constitute an advanced drought tolerant sorghum trial for evaluation in at least three ESA countries. Stay-green, indicated by maintenance of green stems and upper leaves when water is limited during grain filling is a mechanism of drought tolerance. Two sorghum inbred lines (B35 and E36-1) are being used as donor parents for transferring the major stay-green QTL into four farmer preferred local sorghum varieties. Twenty-nine (11 from B35 and 18 from E36-1) BC<sub>1</sub>F<sub>1</sub> individuals containing target QTLs have been backcrossed to their respective recurrent parents for developing BC<sub>2</sub>F<sub>1</sub>s and this was linked to capacity building of NARS collaborators. In groundnut, three elite Spanish test lines ICGV-SM 01513, ICGV-SM 99541 and ICGV 93437 plus two released Spanish checks JL 24 and ICGV-SM 99568 in short duration backgrounds were evaluated in Malawi, Tanzania and Mozambique. The selected materials from each country will be tested on farm to identify farmer preferred varieties for release.*

*Participatory approaches (mother baby trials) are currently being deployed to evaluate integrated improved sorghum cultivars and natural resource (soil and water) management to ensure that varieties and their management are consistent with the local environment and resources of the farmers for increased crop water productivity. Grain yields increased with application of water management technologies and deep trenches were the best water management technologies and Chitichi was the best performing variety followed by improved sorghum varieties (Macia and SV4) and the other local variety Sila.*

*Simulation analysis using APSIM to examine the performance of pigeonpea, and groundnut in rotation with maize under various soil, climate and management practices and their effect on natural resource base indicated interactions of various biophysical factors on crop production and quality of the resource base. In these environments, the major limitation to realizing the genetic potential of crops is soil fertility since water is not the major limiting factor, and hence it is possible to achieve two- to- threefold increase in yields with the use of improved varieties and fertilizer inputs.*

**2007 4.3.1: Drought tolerant varieties of sorghum for evaluation with water management technologies identified**

A short and intense rainy season, with highly unreliable rainfall and frequent droughts are the most common crop-water related stresses experienced in Zimbabwe in southern Africa. The challenge to produce more food under increasing water scarcity has led to the need for increased crop water productivity to increase production. The ICRISAT program in ESA has identified a number of sorghum and millet breeding lines and released

varieties that are early maturing as a mechanism to escape terminal drought. Soil and water management technologies are also available including tied ridges, deep trenches, pot holing and Zai trenches together with well tested participatory approaches (eg, farmer field schools, mother and baby approach). It is imperative that these participatory approaches are deployed in efforts to integrate crop breeding products and natural resource (soil and water) management to ensure that varieties and their management are consistent with the local environment and resources of the farmers and their community. This strategy was used to evaluate improved drought tolerant and local sorghum varieties with water management technologies using the mother baby approach. Other management practices such as land preparation and various soil types were also evaluated. Data was collected from about 500 mother baby trials and the combined analyses included 10 varieties (5 improved and 5 local) and 8 water management technologies. On the participatory approaches, trial types (mother vs baby) gave different yields with mother trial performance being better, and this is attributed to the fact that mother trials are better managed than baby trials. Varieties were significantly different with Chitichi, a local sorghum variety, performing better ( $2.6 \text{ t ha}^{-1}$ ) whereas the mean of the improved varieties was about  $1.0 \text{ t ha}^{-1}$ . Across varieties, deep trenches were the best water management technologies and there were no significant interactions between water management and varieties. Two improved sorghum varieties (Macia and SV4) as well as two local varieties (Chitichi and Sila) are the best bet sorghum varieties for the Limpopo basin. The variety Chitichi has a unique capability of ratooning and completing the reproductive cycle with high yields even after a very severe drought. Future breeding activities should include these two local varieties especially in efforts to develop drought tolerant varieties by integrating conventional breeding with MARS.

MA Mgonja and S Kudita

#### *2007 4.3.2: Interaction between farmers, and agricultural concession companies supported through accelerated technology exchange*

One of the objectives of this project is to increase productivity while improving quality of the natural resource base through use of complementary crops in the farming systems of smallholder farmers in Mozambique. At present, very little information is available on how different crops perform under various management practices and on how the management practices impacts on natural resource base. Such information is vital for identifying Good Agricultural Practices that can increase and sustain productivity. The project activities were implemented as pilot in Nampula, Tete and Zambezia Provinces, and focused on the complementary crops used by the concession companies, namely maize, groundnuts, pigeonpea and soybeans. Simulation analysis using crop simulation model APSIM was carried out to examine the performance of pigeonpea, and groundnut in rotation with maize under various soil, climate and management practices and their effect on natural resource base.

Despite the data limitations and model assumptions, the simulation analysis provided valuable insights into the interaction of various biophysical factors on crop production and quality of the resource base. The simulation results indicated that in these environments the major limitation to realizing the genetic potential of crops is soil fertility. This is because the region receives more than 450 mm rainfall during the crop season (Dec-Mar) which is fairly reliable ( $CV < 20\%$ ). Since water is not the major limiting factor, it is possible to achieve a two to three fold increase in yields with the use of improved varieties and fertilizer inputs. Incorporation of legumes into the existing maize cropping systems either as a rotation or intercrop resulted in significant financial (at the prevailing grain prices of US\$0.13/kg pigeonpea and US\$ 0.4/kg of groundnut) and soil fertility (equivalent to 50 kg/ha urea application) benefits making it an attractive option. Intercropping maize with pigeonpea seems to be a win-win option since it can be done without any reduction in the maize yields due to the current farmer practice of using low maize plant populations.

KP Rao and C Dominguez

#### *2007 4.3.3: Drought tolerant sorghum lines from conventional selection evaluated in preliminary replicated trial*

Mahube is an early (45 to 50 days to flowering and 90-100 days to maturity) pure line sorghum variety selected from introduced mixed germplasm bulk IS 2923, indexed as SDS 2583 in ICRISAT's germplasm collection in Matopos. It was released in Botswana in 1994 and is the earliest maturing improved sorghum variety in the entire SADC region. Due to extreme earliness, it has excellent terminal drought escape mechanism with some seedling drought tolerance and attains yields of  $1.5$  to  $3 \text{ t ha}^{-1}$ .

Stable  $F_8$  progenies derived from crosses between Mahube and improved dry lowland lines were constituted into a preliminary drought tolerant sorghum variety trial and planted at Kiboko in April 2007 rainy season. Out of the 22 test lines, 13 attained grain yields between  $3.69$ - $5.47 \text{ t ha}^{-1}$ , way above a trial mean of  $3.35 \text{ t ha}^{-1}$  and also

above the best check parent Macia (3.66 t ha<sup>-1</sup>). The parent variety Mahube flowered in 66 days and had a yield of 0.36 t ha<sup>-1</sup> whereas the high yielding progeny lines flowered between 62 and 70 days. One of the highest yielding lines (IESV 07008DL) flowered in 62 days yielding 4.28 t ha<sup>-1</sup>. Selections made have been constituted to form an advanced drought tolerant sorghum trial and planted at Kiboko and Kampi ya Mawe in Kenya and sets sent to Tanzania, Mozambique, South Africa and Malawi. In addition to evaluation under rainfed conditions, these materials need to be exposed to imposed terminal drought to determine their potentials under those conditions.

MA Mgonja, EO Manyasa, S Kudita and E Muange

#### **2009 4.3.1: Efficiency and effectiveness of MAS for stay green in sorghum determined**

Drought is considered to be the primary causes of yield reductions in crops in sub-Saharan Africa. Two distinct drought-stress responses have been identified in sorghum: a pre-flowering drought response that occurs prior to anthesis and a post-flowering drought response that is observed when water limitation occurs during the grain-filling stage. Genotypes resistant to post-flowering drought stress are called 'stay-green'. Stay-green is the best-characterized component of terminal drought tolerance in sorghum. Two sorghum inbred lines (B35 and E36-1) were used as donor parents for transferring the major stay-green QTL into four farmer preferred local sorghum varieties (Teshale, Meko, 76#123 and Gambella) in Ethiopia. A sorghum breeder at Melkassa Research Station in Ethiopia (Dr Tesfaye Tesso) developed over 1,000 BC<sub>1</sub>F<sub>1</sub>s from 8 different crosses using B35 and E36-1 as donor parents and the 4 local varieties as recurrent parents. Leaf materials from 552 BC<sub>1</sub>F<sub>1</sub>s as well as the 2 donor and 4 recurrent parents were collected in 90% ethanol in July at Melkassa Research Station and brought to the BecA lab in Nairobi for molecular analysis. DNA was extracted from each sample and 164 microsatellite markers were screened for polymorphism between parents. A total of 64 microsatellite markers were used for foreground selection, with the number of markers ranging from 3 to 12 per cross. The presence of each target QTL in the BC<sub>1</sub>F<sub>1</sub>s was checked using at least two polymorphic foreground markers that mapped close to the target chromosomal region. This helped to identify heterozygote individuals that are carriers of at least one target QTL from B35 or E36-1. At least one BC<sub>1</sub>F<sub>1</sub> plant per cross that contained the target QTL from the donor parent on carrier chromosome and the recurrent parent genome on non-carrier chromosomes was advanced to BC<sub>2</sub>F<sub>1</sub>s. Twenty nine (11 from B35 and 18 from E36-1) heterozygote BC<sub>1</sub>F<sub>1</sub> individuals containing target QTL were finally backcrossed to their respective recurrent parents for developing BC<sub>2</sub>F<sub>1</sub>s. Two days training was provided for 2 NARS breeders and 2 research technicians at Melkassa Research Station in Ethiopia on DNA sampling protocols, including the right age for collecting leaf samples from breeding lines and sampling methods (FTA card, silica gel, acetone and ethanol).

K Semagn, T Teso, D Hoisington, and CT Hash

#### **2008 4.3.2: At least 3 farmer/market preferred groundnut varieties incorporating drought tolerance in short duration background released in 2 to 3 ESA countries**

NARS collaborators, traders and farmers with technical and financial assistance from ICRISAT continue with evaluation of improved groundnut varieties and elite lines to identify the most adaptable and acceptable materials for release and cultivation by farming communities. Three elite Spanish test lines ICGV-SM 01513, ICGV-SM 99541 and ICGV 93437 alongside two released Spanish checks JL 24 and ICGV-SM 99568 were evaluated on-farm in Mchinji and Nkhotakota districts. Spanish materials ICGV-SMs 01513 and 99541 yielded significantly higher than JL 24 (37 and 7%, respectively). Farmer ranking also revealed that farmers in Malawi prefer varieties with tan colored kernels. In Tanzania, preference ratings indicated farmer's preference for ICGV 99555 and ICGV SM 99557. The two varieties showed high yield compared to Pendo, the currently released variety. Results from Mozambique suggest outstanding performance from 3 breeding lines, ICGV-SM 99568, ICGV-SM 99541 and ICGV-SM 01513. The materials are already under on-farm evaluation and at a pre-release stage.

ES Monyo, M Osiru, D Kandyampakeni and H Charlie

### **Output 4.4: Increased knowledge to biofortify sorghum by means of transgenic and non-transgenic germplasm with enhanced micronutrient levels; and a better understanding of risk management associated with transgenics through environmental risk assessments.**

#### **Summary**

*Environmental Risk Assessment is an important pre-requisite for deploying genetically engineered sorghum, and this requires an understanding of the crop species and varietal diversity at the local scale level. The*

*hypothesis to be tested in a local crop-weed survey is that introgression is preferential among wild/weed populations and certain sorghum varieties. Progress in integration of molecular approaches in gene flow included evaluation of 21 SSR markers in 21 elite sorghum varieties released in ESA, 14 landraces collected from western Kenya and 5 wild/weedy sorghums. It was inferred that these markers could detect polymorphism among cultivated and wild/weedy sorghums and thus could be used for gene flow studies.*

**2007 4.4.1: 10 molecular markers identified for gene flow studies in sorghum identified**

ICRISAT scientists working in the Biosciences for Eastern and Central Africa (BECA) laboratories have optimized DNA extraction and high-throughput PCR and ABI genotyping for routine use in various research projects. Thus, the required molecular biology facilities were available at the BecA laboratory and they provided the required genotyping facilities for this project.

Recently, scientists from ICRISAT and CIRAD working in a collaborative project under the Generation Challenge Program identified 39 SSR markers that are extremely robust and provide highly repeatable fingerprints across a wide range of sorghum germplasm. ICRISAT scientists in India recently completed the fingerprinting of 3000 sorghum accessions using 24 out of the 39 robust SSR markers. Primer sequences, labeled primers and optimized PCR conditions for 21 out of the 24 SSR markers are available in the BecA laboratory. The 21 SSR markers were evaluated in 21 elite sorghum varieties released in ESA, 14 landraces collected from western Kenya and 5 wild/weedy sorghums in order to ascertain their polymorphism and thus their utility in gene flow studies. Seeds from all the genotypes were germinated in trays and DNA extracted from 10-day old seedlings using the CTAB method. All the 21 SSR markers were easily scored with each marker giving 2-19 distinct bands. A total of 187 bands were identified. It was inferred that these markers could detect polymorphism among cultivated and wild/weedy sorghums and thus could be used for gene flow studies.

SG Mwangi and MA Mgonja

*2007 4.4.2: Agro-ecosystem characterization and genetic sampling on the Intensive Study Site (South Meru District in Kenya) completed and reported*

Environmental Risk Assessment is an important prerequisite for deploying genetically engineered sorghums. An exhaustive system-based survey on crop species and varietal diversity at the local scale was conducted in the project Intensive Study Site, Meru South District, Eastern Province (8 km by 8 km). A total of 372 farmers were interviewed and detailed information on cropping system diversity, sociological and economical status of households was recorded and all farms were mapped. Using multivariate approaches and the analytical framework of community ecology, we were able to show that several types of cropping systems occur in the site. Cropping system is not only structured along an environmental (elevation) gradient, but also according to socio-economic factors such as access to market and integration in extension/NGO/church supported seed system programs. The wild/weedy sorghums are not randomly distributed among these different cropping systems. Twelve sorghum fields were found to be infested by weedy sorghums, 3 fallows and one “natural habitat” had wild/weedy sorghums present. Five individuals of all sorghum varieties cultivated in each field and 25 wild/weedy sorghums for each of the 16 populations were collected in July 2007. They were germinated and the DNA isolation for a total sample of 500 individuals has started (to be completed in December 2007). The hypothesis we want to test in this local crop-weed introgression survey is that introgression is preferential among wild/weed populations and certain sorghum varieties.

F Sagnard, K Semagn and S de Villiers

*2008 4.4.2: Paper accepted on sorghum crop-to-wild introgression rates in contrasted Kenyan agro-ecological regions*

The DNA isolation of the 450 wild, weedy and cultivated sorghums collected at the Kenya scale was completed. The whole collection will be completed in December 2007. The description of the collection is made in “Ecogeographic distribution of wild, weedy and cultivated sorghums in Kenya” by Mutegi E. et al., for which the final will be submitted in the first week of January 2008.

Two PhD students working with ICRISAT have used this collection to assess the genetic relationships between the wild, weedy and cultivated gene pools (inter-varietal/population level), and the demo-genetic dynamics of wild and weedy sorghum populations across Kenya (intra-population level). At the inter-varietal level, seventy-five percent of the collection was genotyped for 30 SSR markers belonging to the Generation Challenge

Program set, in the BECA lab. At the within wild sorghum population level, 50 populations (out of 60) of 25 individuals were genotyped for 18 SSR at the University of Hohenheim.

The preliminary results confirm *i*) the low genetic differentiation among the wild/weedy and cultivated sorghums, and *ii*) geographic patterns with a clear differentiation of wild and cultivated sorghums from the Lake Turkana region. They suggest that crop-to-wild gene flow occurs in sorghum and that the gene flow patterns might vary among regions and agro-climatic zones.

F Sagnard, K Semagn and S de Villiers

#### **Output 4.5: Technologies and knowledge to reduce aflatoxin contamination at different stages of the groundnut crop cycle developed and disseminated to partner NARES, traders and processors in ESA with associated capacity building for enhanced food and feed quality and facilitated adoption and impact from technological changes**

##### **Summary**

*Several mycotoxins contaminate food crops of the poor in the SAT. Among these, aflatoxins, which are toxic, carcinogenic, and immuno-suppressive substances, contaminate groundnut, maize, cotton, chilies, and many other agricultural commodities. Management of contamination of food and food products by mycotoxins has proven to be a difficult challenge in developing countries due to a lack of awareness, stringent food safety regulations and their implementation, environmental conditions and farming practices that are conducive for the contamination. Mycotoxin testing facilities consisting of ELISA and various protocols have been purchased for Kenya, Malawi and Mozambique and this is linked to capacity building of stakeholders. A farmer field school concept was initiated to work with groundnut farmers in Malawi focusing on aflatoxin integrated management options (varieties, time of planting and water management) in the farmers' cropping systems. Many farmers were aware of the aflatoxin problem and that aflatoxin contamination could be mitigated by use of the box ridges as opposed to use of the open ridges for water management. On-farm demonstrations were also established on improved groundnut varieties together with those commonly used by farmers and seed fairs and field days were held to provide opportunity for farmers to observe a range of elite varieties available and potentially new materials in the pipeline. Production of source seed of improved cultivars targeted seed availability for further evaluation and for pursuance of alternative seed production and distribution system to enhance adoption.*

##### *2007 4.5.1: Mycotoxin testing facilities and protocols developed in Kenya, Malawi and Mozambique*

In 2007, a mycotoxin testing facility in Kenya was setup in a dedicated room adjacent to the soils laboratory at the World Agroforestry Center in Nairobi. The testing facility consists of an ELISA reader and associated equipment needed for the reception, grinding and extraction of mycotoxins from crop samples. A new ELISA reader was procured for the existing mycotoxin testing facility at Chitedze Research Station near Lilongwe in Malawi. The third mycotoxin testing facility was established at the Zonal Research Center in Nampula, Mozambique in 2005 and additional chemical supplies provided to this laboratory in 2007.

Two staff from Kenya, a postgraduate student from the Kenya Agricultural Research Institute (KARI) and a technician working with CABI, were sent to ICRISAT-Patancheru for a two-week training course in mycotoxin analysis and are now fully conversant with the procedures needed to sample, extract and analyze mycotoxins from different grains. A technician from the National Smallholder Farmers' Association (NASFAM) in Malawi attended the same training course so that in Malawi there are now two fully-trained technicians to operate the existing mycotoxin facility at Chitedze Agricultural Research Station near Lilongwe. Technicians from the Instituto Investigaçã de Agraria de Moçambique (IIAM) were trained at ICRISAT-Patancheru in 2005. An aflatoxin testing laboratory was acquired and installed at Agronomic Post of Nampula province, and will be operated by IIAM senior staff that were trained in ICRISAT, India. A business plan for ICRISAT-Nairobi has been developed based on the protocols from ICRISAT-Patancheru. This business plan will be modified for the ICRISAT-Lilongwe and Nampula facilities so that a system of full-cost recovery can be implemented in 2008. Options for placing the mycotoxin testing facility into an Agri-Science Park in Lilongwe, and in Mozambique are being considered and a business plan for an Agri-Science Park in Mozambique has already been drafted.

RB Jones and C Dominguez

##### *2007 4.5.2: Trainers trained in quality on farm seed production with pre- and post-harvest aflatoxin control measures available in at least 2 ESA NARS*

A farmer field school concept was initiated to work with groundnut farmers in the main groundnut growing districts of Malawi (Mchinji and Nkhosokota). The concept focused on aflatoxin integrated management options in the farmers cropping systems. Use of tolerant genotypes, time of planting (early vs. late) and water management (box versus open ridges) were all demonstrated. Group discussions were regularly held with farmers to assess their awareness. The interaction revealed that many farmers were aware of the aflatoxin problem and associated bitterness of the seed with aflatoxin contamination. They thought that since there are no visible indications of aflatoxin nothing could be done to reverse the low yields and bitterness of affected seeds. It is known that any delay in harvesting the crop under end of season drought could severely reduce yield and increase aflatoxin contamination. They however understood from the demonstrations that aflatoxin contamination could be mitigated by better water management through use of box ridges as opposed to open ridges.

Two one-day training workshops were organized by ICRISAT and the National Smallholder Farmers Association of Malawi (NASFAM) in 2007 with the objective of strengthening capacity of NASFAM Association Field Officers (AFOs) in quality on-farm seed production and maintenance. Knowledge of available pre-harvest and post harvest aflatoxin control measures were discussed. Thirteen front line officers participated in the training workshops, six in Mchinji and seven in Nkhosokota. Training materials developed for the courses are available for future use. In Tanzania, similar trainings were conducted in November 2007. Over 20 extension officers and 37 farmers who are members of Farmer Research Groups in 20 established Farmer Field Schools centers participated. The training covered all aspects of quality seed production and crop production techniques as per original plan.

E S Monyo, M Osiru, D Kandyampakeni and H Charlie

#### *2007 4.5.3: Production of source seed and pursuance of alternative seed production and distribution system to enhance adoption*

A total of 295 lines were multiplied in quantities ranging from 2 – 5 kg under close supervision to maintain purity and avoid admixtures. The seed will serve as source for breeder seed and entries for collaborative trials with NARS in ESA. Breeder seed of released varieties in Malawi and pre-released varieties in Tanzania and Mozambique were multiplied in smaller quantities at Chitedze Agricultural Research Station. The varieties included ICG 12991, ICGV-SM 90704, ICGV-SM 99568 and Chalimbana for Malawi; besides released varieties, pre-released varieties such as ICGV-SM 99541, ICGV-SM 01513, ICGV-SM 99537, and ICGV 93437 were multiplied in quantities ranging from 100kg – 500kgs. ICGV-SM 99541, and ICGV-SM 01513 are under on-farm testing in Mozambique and Zimbabwe, where as ICGV-SM 99537, and ICGV 93437 are released in Zimbabwe and South Africa but also under evaluation in Mozambique National Trials. 200 kg breeder seed of the farmer/market preferred groundnut variety Pendo for Tanzania was produced during the season. At least one ton of breeder seed of ICGV-SM 99568 and ICGV-SM 90704 has been produced in Malawi as source for foundation seed for collaborating NARS and other partners.

Seed fairs were organized in Tanzania during 1-6 July 2007 in Mpeta and Mangaka villages in Masasi district. About 2000 people in total attended. Farmers were provided with extension materials including leaflets, video films and interacted with exhibitors. NGOs are currently being encouraged to participate in the seed production process and the seed fairs were used as an avenue of bringing these stakeholders together.

Nine Farmer Field Days were conducted in Malawi to popularize and disseminate promising groundnut production technologies to farmers and collaborating stakeholders. Groundnut being a self pollinated crop, seed exchange between participating farmers was one of the most important technology exchanges that occurred between farmers. Three hundred and ninety-three farmers and stakeholders including government and non-governmental organization (NGO) extension workers, researchers, local leaders such as chiefs and village headmen, attended the field days and benefited from this event.

In Tanzania, two field days were organized with total participation of 171 farmers, 83 men and the rest women. The field days in Tanzania were organized before the seed fairs to expose farmers to the range of varieties that would be ultimately made available for them during the seed fairs.

ES Monyo, M Osiru and H Charlie

#### *2008 4.5.2: IPG knowledge on the extent of mycotoxin contamination of groundnut in Malawi and Kenya with appropriate capacity development disseminated regionally*



On-farm demonstrations were established in two of Malawi's groundnut growing districts of Mchinji and Nkhosokota. The objectives were to a) compare (and demonstrate) improved groundnut varieties with the varieties commonly used by farmers; b) provide opportunity for farmers to observe first hand range of elite varieties available and potentially new materials in the pipeline; and c) collect relevant information from farmers and industry that may strengthen the case for release. The participatory groundnut variety trial involved five Virginia (Chalimbana, ICGV – SM 90704 (Nsinjiro), CG 7, ICGV-SM 01708 and ICGV-SM 88710) and five Spanish (JL24 (released in Malawi as Kakoma), ICGV-SM 99568, ICGV-SM 99541, ICGV-SM 01513, and ICGV-SM 93437 (commonly known as Nyanda) varieties. Farmers who grew the trials evaluated the plots at regular intervals visually. Other farmers from the vicinity visited the trials before harvest and scored each plot for its desirability. Studies revealed significant differences in Kernel and pod yield amongst varieties tested. For example, accession ICGV SM01513 produced the highest kernel yield of 1146 kg ha<sup>-1</sup>. Of specific interest were promising Virginia materials ICGV-SMs 01708 and 88710 and Spanish materials ICGV-SMs 01513 and 99541 which yielded significantly higher than JL 24 (57 to 63% increase in yield over JL 24). Tasting evaluations indicated that farmers still have a liking for variety Chalimbana. Farmer ranking also revealed that farmers in Malawi prefer varieties with tan colored kernels.

ES Monyo, M Osiru, D Kandyampakeni and H Charlie

## List of Publications in 2007

### Journal papers:

**Lenné JM, Takan JP, Mgonja MA, Manyasa EO, Kaloki P, Wanyera N, Okwadi J, Muthumeenakshi S, Brown AE, Tamale M and Sreenivasaprasad S.** 2007. Finger millet blast disease management: A key entry point for fighting malnutrition and poverty in East Africa. *Outlook on Agriculture* Vol. 36, No. 2: 101-108.

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### Conference Papers

**Manyasa EO, Silim SN, Christiansen JL and Githiri SM.** 2007. Diversity in Tanzanian pigeonpea [*cajanus cajan* (L.) Millsp.] Landraces. *In* Proceedings of the First International Conference on Indigenous Vegetables and Legumes. Prospectus for Fighting Poverty, Hunger and Malnutrition (Chadha ML, Kuo G and Gowda CLL, eds), Hyderabad, India, 12-15 December 2006. *Acta Horticulture* 752:169-174.

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**Osiru M, Monyo E, Waliyar F and Harvey C.** 2007. Strategies for Management of the groundnut rosette disease in Sub-Saharan Africa. Fourth Annual General Meeting of the Forum for Agricultural Research in Africa. 10– 7 June, 2007. Sandton. South Africa.

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#### **Information Bulletin:**

**Waliyar F, Kumar PL, Ntare BR, Monyo E, Nigam SN, Reddy AS, Osiru M and Diallo AT.** 2007. A Century of Research on Groundnut Rosette Disease and its Management. Information Bulletin no. 75. Patancheru 502324, Andhra Pradesh, India:International Crops Research Institute for the Semi-Arid Tropics. 35pp. ISBN 978-92-9066-501-4. Order code: IBE 075

#### **News Articles:**

**Mgonja MA.** 2007: High hopes with sorghum hybrids. SATrends Issue 81.

**De Villiers SM.** 2007: Indian recipe for robust pigeonpea. SATrends Issue 79

## **Project 5:** **Producing more and better food at lower cost of staple cereal and legume hybrids in the Asian SAT (sorghum, pearl millet and pigeonpea) through genetic improvement**

*MTP Output Target 2007 5.1.1 PM*

*More than 150 potential hybrid parents characterized for morphological diversity*

**Characterization for Distinctness, Uniformity and Stability (DUS) traits:** Two-season characterization data of 99 A/B pairs (1981 to 2004-series A/B pairs) for 26 morphological traits (recorded following DUS guidelines) from replicated trial were compiled for documentation. The key characteristics of each A/B pair along with their photographs have also been completed. In order to document the designated restorer lines, about 120 lines were characterized for 26 DUS traits from a replicated trial during the rainy season. The data are yet to be computerized and the second-season characterization will be carried out during the 2008 postrainy season.

DNA was extracted from 127 B-lines and 147 R-lines and a working concentration of 2.5ng/  $\mu$ l was prepared. PCR optimization for 20 SSR markers was done following Taguchi method. PCR products are ready and will be run through ABI 3100 to get the allelic peaks, which will be further run through GeneScan and Genotyper softwares to generate information on alleles per SSR marker.

**Morphological diversity in designated seed parental lines:** Ninety-nine designated cytoplasmic male-sterile (A) lines along with their maintainer (B) lines in three different CMS backgrounds viz., A<sub>1</sub> (63), A<sub>4</sub> (35) and A<sub>epg</sub> (1) were characterized in a replicated trial for 26 morphological traits (including 17 essential traits) following DUS guidelines during the 2005 summer and rainy season.

The cluster analysis based on 10 quantitative traits grouped 99 maintainer lines into two major clusters at 20% dissimilarity coefficient with ICMB 04111 and ICMB 04777 clustering together in a distinct cluster and the remaining clustering in the second cluster. However, at 9% dissimilarity level, the inbred lines clustered into 8 distinct groups and this has relevance to the respective parentage of these lines. All the lines that grouped in a cluster were similar either by parentage or they were of similar maturity. Some of the lines with similar parentage also grouped in different clusters, which is mainly due to differences in their maturity or plant height. The principal component analysis showed that days to 50% flowering, plant height, spike length and seed weight contributed about 67.3% of the variation present between these 99 B-lines with days to 50% flowering ranging between 41 and 60 days, plant height between 62 to 136 cm, spike length between 12 to 35 cm and 1000-grain weight between 7 to 13 g.

The molecular diversity will be assessed once the genotyping is completed on these lines using 20 SSR markers.

**Within-line diversity:** To assess the within line genetic variation, ten phenotypically diverse B- and 10 R-lines were planted during rainy season and 40 selfed plants were randomly selected from each line and harvested separately. These will be planted again individually during the 2008 postrainy season for morphological characterization and genotyping with 20 SSR markers.

KN Rai and Ranjana Bhattacharjee

*MTP Output Target 2007 5.1.1 PP: Cytology and genetics of the A<sub>4</sub> CMS system and its fertility restorers characterized*

Microsporogenesis and genetics of fertility restoration of A<sub>4</sub> cytoplasmic-nuclear male-sterility system in the pigeonpea was studied during the year 2006. The process of microsporogenesis in the male-sterile (ICPA 2039) and its maintainer (ICPB 2039) plants was normal up to the tetrad formation stage. The tapetal cells in the male-sterile anthers degenerated soon after tetrad formation, resulting in shriveled and degenerated microspores (Figures I-VIII). In the maintainer plants, the tapetal cells were normal and microspores were functional. The breakdown of tapetum before the completion of microsporogenesis was the major cause for the expression of male-sterility in A<sub>4</sub> CMS system.

Five crosses were attempted to study the genetics of fertility restoration for A<sub>4</sub> CMS system. All the F<sub>1</sub> plants in five crosses were fully fertile indicating the dominance of fertility restoring gene(s). The F<sub>2</sub> and BC<sub>1</sub>F<sub>1</sub> progenies of the crosses involving A<sub>4</sub> CMS line segregated for male-sterility and fertility. Among the five

crosses studied, three (ICPA 2039 × ICP 12320, ICPA 2039 × ICP 11376, and ICPA 2039 × HPL 24-63) segregated in a ratio of 3 fertile : 1 sterile in F<sub>2</sub> generation whereas in the backcross generation a segregation of 1 fertile : 1 sterile was observed. This indicated the monogenic dominance nature of the fertility restoring gene. The pooled values over the three crosses also exhibited goodness of fit for 3 fertile : 1 sterile ( $\chi^2 = 0.11$ ) ratio in F<sub>2</sub> generation and 1 fertile : 1 sterile ( $\chi^2 = 1.06$ ) in backcross generation. The F<sub>2</sub> and backcross populations of cross ICPA 2039 × ICP 10650 segregated in the ratio of 15 fertile : 1 sterile ( $\chi^2 = 0.31$ ) and 3 fertile : 1 sterile ( $\chi^2 = 0.44$ ), respectively. This suggested the involvement of two dominant genes with duplicate gene action. The other cross (ICPA 2039 × ICP 13991) segregated in a ratio of 9 fertile : 7 sterile ( $\chi^2 = 2.10$ ) in F<sub>2</sub> generation and 1 fertile : 3 sterile ( $\chi^2 = 3.86$ ) in BC<sub>1</sub>F<sub>1</sub> generation indicating the presence of two complimentary genes for restoring the fertility of male-sterile line.

*MTP Output Target 2007 5.1.2 PP: 6 A4 male-sterile lines and 15 restorer lines with resistance to wilt and sterility mosaic disease developed*

Wilt and sterility mosaic (SM) are the two devastating diseases of pigeonpea in major pigeonpea growing areas worldwide. To address these bottlenecks, specific resistance breeding program was taken up at ICRISAT. The original ICPA 2039 A<sub>4</sub> CMS line was susceptible to both wilt and sterility mosaic diseases. This line was crossed to germplasm lines resistant to wilt and/or sterility mosaic. The resulting F<sub>1</sub>s, which maintained male sterility with resistance to wilt and/or sterility mosaic, were selected. There were six wilt and sterility mosaic resistant male sterile lines, viz., ICPA 2086 (short duration, determinate), ICPA 2043, ICPA 2078 and ICPA 2101 (medium duration, Maruti maturity group, non-determinate), ICPA 2046 and ICPA 2048 (medium duration, Asha maturity group, non-determinate).

On similar lines, a restorer breeding program was initiated by crossing promising susceptible restorers with wilt and/or sterility mosaic resistant germplasm (R×R breeding). The segregating generations were evaluated in the wilt and sterility mosaic disease nursery at ICRISAT-Patancheru during 2006. There are 34 restorer lines with resistance to both wilt and sterility mosaic belonging to the medium maturity group. In the long-duration maturity group one restorer was found to have resistance to both wilt and sterility mosaic. All these wilt and sterility mosaic resistant A- and R- lines are being crossed. The F<sub>1</sub>s of these crosses are being evaluated for fertility restoration, grain yield and other important agronomic traits.

**Evaluation of CMS lines and their restorers for combined resistance to wilt and SM:** A total of 62 short-duration and 67 medium-duration maintainer lines and restorers were evaluated for both wilt and SM resistance in wilt and SM sick plot under artificial epiphytotic conditions following standard field evaluation techniques at ICRISAT-Patancheru. Chopped wilted pigeonpea plants were incorporated every year in the sick plot to maintain a threshold level of wilt fungus, *Fusarium udum*. For successful SM infection, every plant of test entries was leaf inoculated with SM infested leaves using leaf staple technique at two-leaf stage. Susceptible cultivars ICP 2376 for wilt (resistant to SM) and ICP 8863 for SM (resistant to wilt) were planted along with test material, after every ten test rows as indicator rows. Data on the incidence of wilt and SM were recorded at seedling, flowering, pod initiation and at near maturity stages.

Of the 62 short-duration maintainers and restorers, four lines ICPBs 2086, 2101, 2078, and 2089-34 were found asymptomatic for both wilt and SM diseases. Additionally 14 lines (ICPAs 2041B, 2078, 2085, 2090, 2101, 2149, 2161, ICPBs 2040, 2085, 2089-24, 2089-29, 2089-35, 2149, 2164,) were asymptomatic to SM. Two lines (ICPA 2086 B, ICPA 2086 W) were resistant to wilt and SM (<10%).

Of the 67 medium-duration maintainers and restorers, five lines (ICPBs 2032, 2072, ICPHs 3423, 3442, and 3450) were asymptomatic to both wilt and SM and four lines (ICPAs 2049, 2070, ICPB 2048, Sriganesh B) were asymptomatic for SM alone. Further, 24 lines for both wilt and SM, one line (ICPA 2047) for wilt and eight lines (ICPAs 2040, 2091, ICPBs 2047, 2051, 2091, 2092, ICP 7035, Vaishali) had a resistant reaction for SM.

S Pande, KB Saxena and RK Srivastava

*MTP Output Target 2007 5.2.1 SOPM: Protocol for consistent and reliable P-acquisition data applicable to large numbers of entries developed for proto-drought tolerance screening in pearl millet*

A protocol has been developed based on the trials and analysis done in the past few years with regard to screening of tolerance to low soil P conditions in pearl millet. This protocol has been developed based on the fact that pearl millet seeds are small and that plant establishment is a key factor to a successful performance

under low P conditions. To get uniform sowing depth, a template making holes of a standard depth is used, in which seeds are placed. Several seeds were usually sown per hill, and then thinned to one seedling per hill. It was observed that thinning was affecting the development of the remaining seedlings (probably by disturbing roots of the remaining seedling). Therefore, 9 seeds are now planted per pot, one each into an individual hole made with the template, and most uniform 3 seedlings are retained. The protocol is also based on an observation that growing 3 plants per replicate the pot helps in decreasing the replicate-to-replicate variation. We are also aware of a genotype  $\times$  nitrogen interaction effect under low P soil, which has to be taken into account at the time of screening for low-P tolerance (a choice has to be made and repeat experiment should use the same N source). Finally, we have found that a small difference in soil Olsen P value could bring about large differences in the response of pearl millet plants. Therefore, the same soil lot is used for each experiment, and this lot is first homogenized with a concrete mixer prior to preparing the soil:sand mix (1:1 v/v).

This protocol is now routinely used to screen genotypes for their tolerance to low soil P conditions. A set of experiments has been performed using 20 pearl millet inbred parents and appears to be working well (little experimental error), even with small seeded inbred lines from  $F_6$  generation. This protocol has also been tested with testcross hybrids made from these 20 inbred parents onto 4 different testers. We obtained very good data with the new protocol (mixing of soil batch with concrete mixture, uniform sowing depth with template, 3 plants per pots), and cv under low P around 15% only. In this experiment, we found a strong relation ( $r^2 = 0.55$  in RP1, and  $r^2 = 0.36$  in RP2) between the biomass yield under low P and the biomass yield under control conditions (no P limitation), which indicates that plant vigor explains part of the performance under low P. Therefore, the regression equation was used to calculate an estimated biomass yield,  $\hat{Y}_s$ , under low P, from which residuals were calculated as  $Y_s - \hat{Y}_s$ . These residuals would then account for low P tolerance per se. Previous screening had shown some genotypic contrast between LGD 1-B-1-10 (low biomass under low P) and ICMP 85410 - P7 (high biomass under low P), and between 81B - P6 (low biomass under low P) and ICMP 451 - P8 (high biomass under low P). We found similar differences here based on biomass. However, the residuals (after removing the component of the variation that account for growth potential) were lower for ICMP 85410 - P7 than for LGD 1-B-1-10, and the residual for ICMP 451 - P8 were only slightly higher than 81B - P6. These data indicated that the range of variation for low P tolerance between these two pairs of inbred parents was unsuitable for QTL mapping of low P tolerance. By contrast we found a good contrast in the residuals between inbred ICMP 451 - P6 (tolerant) and H 77/833-2-P5 (NT) (sensitive), and between PRLT 2/89-33-Bulk (tolerant) and H 77/833-2-Bulk (sensitive).

The current orientation in these screening would be to enlarge the range of variation available in the parental lines of existing populations for tolerance to low P soil. We also used that protocol to investigate the effect of either the application of 1000  $\mu$ L of a 32 mM  $\text{KH}_2\text{PO}_4$  solution (equivalent to about 10 times the amount of P in a pearl millet seed), or a seed coating at different rates (with a target of about 10 times the amount of P per seed, equivalent to about 0.01 mg P. The seed coating application would correspond to 170 g of granular  $\text{KH}_2\text{PO}_4$  per kilogram of seeds. The response of plant growth to these applications appears to be very promising and these data are summarized in a paper draft that will be submitted for publication.

Vincent Vadez

*MTP Output Target 2007 5.2.2 SOPM: Protocol for consistent and reliable estimation of abscisic acid (ABA) content of drought-stressed tissues developed as an aide to drought tolerance screening in pearl millet*

This protocol was developed with the help of the mycotoxin laboratory and used an ELISA technique. The preliminary evaluations were done on groundnut leaves and later adapted to pearl millet leaves. Free ABA was estimated in the first fully developed leaves of every plant. ABA was assayed by competitive enzyme-linked immuno-sorbent assay (ELISA) according to method of Tuberosa et al. (1982?) with minor modifications. Polyclonal antibodies were raised against antigen - ( $\pm$ ) cis-trans ABA (*Sigma Aldrich*) previously conjugated through its  $C_1$  carboxyl site to a carrier protein bovine serum albumin (BSA) adopting the method of Weiler (1984). Presence of antibodies to the hapten ABA was checked by standard methods. Cross reaction of polyclonal antibodies with BSA to avoid their non-specific reaction was carried out before its use for ELISA. After coating ELISA plates with antigen, plates were loaded with 1% milk to minimize non-specific binding. The antigen coating dilution, antibodies and alkaline phosphatase-linked secondary antibodies dilutions were chosen, so that under assay conditions, absorbance  $A_{405} = 1.0$  for blank was obtained after approximately 1h incubation with p-NPP substrate. Several spiking experiments to detect recovery of known ABA concentration were conducted to validate this technique. For sample extraction and further removal of bio-chemically inert ABA conjugates used the ethyl acetate fractionation technique according to Ryu and Li (1994).

ABA was first measured in a set of 4 groundnut genotypes that were grown in PVC tubes. The size of these cylinders mimic fairly closely the volume of soil that a peanut plant would have in a field at current sowing density. Plants were grown for 30 days. Fifteen plants per genotype were grown. At 30 DAS, 5 plants per genotype were harvested to assess root depth and root dry weight in the different 15-cm layers. The other 10 cylinders were saturated with water, and 5 plants maintained under well-watered conditions (WW) and the other 5 left with no further irrigation (water stressed, WS). Cylinder weight was recorded on a regular basis, usually every 3 days, providing data on the volumes of water uptake and the related kinetics. We found that 2 genotypes had a “conservative behavior”, with their water uptake decreasing quickly after suppressing irrigation, although these two genotypes (TAG24 and ICGV86031) were able to take up water for about 40 days after stress exposition. Two other genotypes had an “opportunistic behavior” and changed little their pattern of water uptake after stress imposition compare to WW plants, but ran short of water sooner than the other two genotypes. It was then interesting to notice that the first two genotypes had higher ABA levels, whereas the two others had lower ABA level.

ABA concentration in four genotypes differing in the response of their water uptake to water stress exposure.

The ABA measurement has also been used to compare PRLT/89-33 and H77/833-2 under well watered conditions. We found that PRLT/89-33 had higher ABA levels, both during pre-flowering and post-flowering stages. Such differences appeared to be related to a lower rate of water loss per unit of leaf area in PRLT/89-33 compared to H77/833-2. This mechanism would allow PRLT/89-33 to save water from the soil profile when water is available, making it available later on to support grain filling when moisture is limiting.

Vincent Vadez

*MTP Output Target 2007 5.3.1: Correlations of high grain Fe (40-50 ppm) and Zn (30-40 ppm) contents with grain yield and agronomic traits estimated for sorghum hybrid parents*

**Core collection evaluation for micronutrient density:** All the 2974 sorghum core germplasm accessions were planted during the 2005 postrainy season and 1401 accessions were assessed for their grain Fe and Zn contents and 153 accessions were selected. Remaining accessions (1062 accessions barring 511 which are highly photoperiod-sensitive) whose grain Fe and Zn contents could not be estimated were planted during 2006-07 postrainy season to assess the genetic variability. For the sake of convenience, the accessions were evaluated (in contiguous blocks) in three separate groups classified based on days to 50% flowering (early:  $\leq 65$  days; medium: 66 to 80 days; late:  $>80$  days). The early group consisted of 322 accessions apart from 4 checks repeated 8 times; the medium group consisted of 460 accessions along with the 4 checks repeated 12 times; the late group consisted of 280 accessions along with 4 checks repeated 7 times. Data were collected on days to 50% flowering, plant height, grain yield, 100-grain weight, grain color, plant agronomic aspect, panicle shape, panicle compactness, glume color, glume coverage, presence/absence of seed sub-coat. The grain samples harvested from selfed panicles of all these accessions and those harvested from open-pollinated panicles wherever sufficient quantities were available were processed for estimation of grain Fe and Zn contents. The results are awaited.

**Evaluation of established hybrid parents for grain Fe, Zn and Al contents:** Identification of hybrids parents with high grain Fe and Zn contents enable faster development of hybrids with high grain Fe and Zn contents and thereby quicker dissemination to the end users. Over the years the sorghum program at ICRISAT developed 758 A-/B-lines and 922 R-lines for various traits. During the 2006 postrainy season seed samples from the 2 replications of 691 hybrid parents (288 B-lines and 403 R-lines) were processed and sent for lab analysis. Data on grain Fe and Zn contents of 164 B-lines was obtained. Results on grain Al content are awaited. From among the 164 B-lines the grain Fe content ranged from 22.4 ppm to 49.2 ppm and the grain Zn content ranged from 15.1 ppm to 37.1 ppm.

**Breeding sorghum for high grain Fe and Zn contents:** In order to identify the transgressive segregants and study the maternal effects for grain Fe and Zn contents, crosses were made between adapted breeding lines and unadapted germplasm lines (contrasting for Fe and Zn contents) in three diallels (diallel set 1: 26 lines contrasting for grain Fe content, set 2: 25 lines contrasting for grain Zn content and set 3: 31 lines contrasting for both grain Fe and Zn contents) in the 2006-07 postrainy season. A total of 223 F<sub>1</sub>s made (75 in diallel set 1, 75 in diallel set 2 and 73 in diallel set 3) will be advanced during the 2007 postrainy season.

**Introgressing grain micronutrients (Fe and Zn)-dense germplasm lines into high yielding breeding lines with elite agronomic backgrounds:** For grain micronutrient dense B-line development, 29 F<sub>4</sub>s were selected

from 23 F<sub>3</sub>s and 62 F<sub>5</sub>s from 75 F<sub>4</sub>s were selected during the 2007 rainy season and for grain micronutrient dense R-line development, 32 F<sub>5</sub>s were selected from 54 F<sub>4</sub>s during the 2007 rainy season. These are being further advanced with selection during the 2007 post rainy season.

From a set of 40 diverse sorghum lines involving parental lines of popular hybrids, varieties, yellow endosperm lines and germplasm lines evaluated during the 2004-05 post rainy season, 22 entries were selected (either Fe >40 ppm or Zn >25 ppm) and further evaluated in a trial along with the check 296B in the 2006-07 post rainy season. From a total of 1401 accessions (core germplasm set 1) evaluated for their grain Fe and Zn contents, 153 accessions with grain Fe content >45 ppm and grain Zn content >35 ppm were selected. Based on grain threshability and for ease of processing, the selected entries were evaluated in two separate trials, a non-threshable lines trial consisting of the 45 entries with 100% glume coverage and resembling the race *bicolor*, and a freely threshable lines trial consisting of remaining 108 germplasm accessions along with six checks in the 2006-07 post rainy season. The grain samples were processed for estimation of grain Fe, Zn and Al contents.

A total of 86 entries consisting of a diverse range of breeding material were evaluated in a triplicated trial during the post rainy season 2003-04 to identify lines with high grain Fe, Zn and  $\beta$ -carotene contents. Forty lines with high and low content were selected and evaluated for agronomic traits and stability of grain Fe, Zn and  $\beta$ -carotene contents during the 2004-05 post rainy season. The correlations based on the two-year data are given in Table 1.

Grain yield and grain-Fe and Zn contents are negatively correlated, but Grain-Fe and -Zn contents are positively (and highly) correlated.

**Table 1. Estimates of correlation coefficients in sorghum breeding and germplasm lines for agronomic and grain traits (2003-04 and 2004-05)**

|                                   | <i>Days to 50% flowering</i> | <i>Plant height (m)</i> | <i>Grain yield (t ha<sup>-1</sup>)</i> | <i>Grain size (g 100<sup>-1</sup>)</i> | <i>Grain Fe (ppm)</i> | <i>Grain Zn (ppm)</i> |
|-----------------------------------|------------------------------|-------------------------|----------------------------------------|----------------------------------------|-----------------------|-----------------------|
| Plant height (m)                  | 0.33                         | 1                       |                                        |                                        |                       |                       |
| Grain yield (t ha <sup>-1</sup> ) | -0.46**                      | -0.03                   | 1                                      |                                        |                       |                       |
| Seed size (g 100 <sup>-1</sup> )  | -0.10                        | 0.28                    | 0.16                                   | 1                                      |                       |                       |
| Fe (ppm)                          | 0.29                         | -0.05                   | -0.48**                                | -0.31                                  | 1                     |                       |
| Zn (ppm)                          | 0.37*                        | 0.42*                   | -0.63**                                | -0.23                                  | 0.66**                | 1                     |

**Core collection evaluation for micronutrient density:** The core collection along with four controls (known for their Fe and Zn contents) were evaluated in augmented design at ICRISAT-Patancheru in the 2005 post rainy season. The accessions were evaluated (in contiguous blocks) as three separate groups classified based on days to 50% flowering (early:  $\leq$  65 days; medium: 66 to 80 days; late: > 80 days). The early group comprising 1095 accessions; the medium group comprising 1128 accessions; and the late group comprising of 751 accessions. The grain samples harvested from selfed panicles of 702 accessions of early maturity, 461 accessions of medium maturity, and 238 accessions of late maturity (making a total of 1401 accessions) were sent for grain Fe and Zn contents estimation. In the core collection also, grain yield and grain-Fe and Zn contents are negatively correlated (though significant; but low in magnitude), but grain-Fe and -Zn contents are positively correlated (Table 2) like in the previous set.

**Table 2. Estimates of correlation coefficients in sorghum germplasm lines for agronomic and grain traits (2005-06)**

|                                   | <i>Days to 50% flowering</i> | <i>Plant height (m)</i> | <i>Grain yield (t ha<sup>-1</sup>)</i> | <i>Grain size (g 100<sup>-1</sup>)</i> | <i>Grain Fe (ppm)</i> | <i>Grain Zn (ppm)</i> |
|-----------------------------------|------------------------------|-------------------------|----------------------------------------|----------------------------------------|-----------------------|-----------------------|
| Plant height (m)                  | 0.54**                       | 1                       |                                        |                                        |                       |                       |
| Grain yield (t ha <sup>-1</sup> ) | -0.02                        | -0.09**                 | 1                                      |                                        |                       |                       |



|                                  |         |         |         |         |        |   |
|----------------------------------|---------|---------|---------|---------|--------|---|
| Seed size (g 100 <sup>-1</sup> ) | -0.31** | -0.15** | 0.08**  | 1       |        |   |
| Fe (ppm)                         | 0.07*   | 0.22**  | -0.16** | -0.12** | 1      |   |
| Zn (ppm)                         | 0.20**  | 0.38**  | -0.21** | -0.15** | 0.61** | 1 |
| n-2= 1393                        |         |         |         |         |        |   |

The remaining 1062 accessions (barring 511 which are highly photoperiod-sensitive) whose grain Fe and Zn contents could not be estimated were planted during the 2006-07 post-rainy season to assess the genetic variability. For the sake of convenience, the accessions were evaluated (in contiguous blocks) in three separate groups classified based on days to 50% flowering (early: ≤ 65 days; medium: 66 to 80 days; late: > 80 days). Correlations for the early and medium group are given in Table 3.

Unlike the previous sets, grain yield and grain-Fe and Zn contents are not highly correlated. However, grain-Fe and Zn contents are positively correlated in core germplasm lines (Table 3) as in the previous sets.

**Table 3. Estimates of correlation coefficients in sorghum germplasm lines for agronomic and grain traits (2005-06)**

|                                   | Days to 50% flowering | Plant height (m) | Grain yield (t ha <sup>-1</sup> ) | Grain (g 100 <sup>-1</sup> ) | Grain Fe (ppm) | Grain Zn (ppm) |
|-----------------------------------|-----------------------|------------------|-----------------------------------|------------------------------|----------------|----------------|
| Plant height (m)                  | 0.50**                | 1                |                                   |                              |                |                |
| Grain yield (t ha <sup>-1</sup> ) | -0.02                 | 0.002            | 1                                 |                              |                |                |
| Seed size (g 100 <sup>-1</sup> )  | -0.57**               | -0.65**          | 0.07*                             | 1                            |                |                |
| Fe (ppm)                          | 0.36**                | 0.46**           | -0.06*                            | -0.64**                      | 1              |                |
| Zn (ppm)                          | -0.03                 | 0.09**           | -0.06*                            | 0.06*                        | 0.39**         | 1              |
| n-2= 853                          |                       |                  |                                   |                              |                |                |

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**Output 5A: Hybrid parents and breeding lines of sorghum, pearl millet and pigeonpea with high yield potential and pro-poor traits in diverse and elite backgrounds, for specific target markets, production environments and research application made available biennially (from 2008) to defined partners with associated knowledge and capacity building in the Asian SAT**

### Summary

*Significant progress was made in the genetic improvement of all three crops with respect to grain yield (as well as stover yield in both sorghum and pearl millet), and resistance to biotic traits like grain mold, stem borer and shoot fly in sorghum; downy mildew in pearl millet; and wilt and sterility mosaic in pigeonpea. Hybrid development and testing no longer remains on ICRISAT's research agenda for the Asia region in sorghum and pearl millet, except for technology demonstration on a limited scale as in the case of sweet sorghum research, and micronutrients and salinity tolerance research both in pearl millet and sorghum. In case of pigeonpea, however, hybrid development and testing constitutes a major activity as the potential of this technology as applicable to on-farm adoption and productivity is still in the technology demonstration phase.*

*In sorghum, 50 maintainer lines (B-lines) of the 50 counterpart male-sterile lines (A-lines) were evaluated for grain yield and grain mold, of which 15 were found having higher grain yield and grain mold resistance levels than the commercial seed parent 296B. In addition, several B-lines at various stages of backcrossing were found having higher grain yield and resistance to grain mold or shoot fly than 296B. Also, several hybrids were identified that had higher grain yield and resistance to grain mold and shoot fly than the commercial hybrid CSH 16. In preliminary and advanced hybrid trials, several hybrids having higher sugar yield than the sweet sorghum hybrid NSSH 104 (used as a control) were identified. In a sweet sorghum variety trial, four varieties*

were identified that had higher sugar yield than the control variety ICSV 74 and had comparable grain yield. Several sorghum lines with high levels of resistance to sugarcane aphid (<4.0 damage rating on 1-9 scale) were identified. Also, lines with combined resistance to sugarcane aphid and midge, and shoot fly and midge were identified. A germplasm line IS 696 was identified as highly resistant to downy mildew (13% disease incidence), which was comparable to QL 3 (control) that had 11% disease incidence. Several sorghum lines were identified that had high levels of resistance to sugarcane aphid.

In the strategic research areas, comparison of sorghum hybrids with several cytoplasmic-nuclear male-sterility (CMS) systems and in the genetic backgrounds having rainy and postrainy (rabi) season adaptation showed that A<sub>1</sub>, A<sub>3</sub>, A<sub>4</sub> (M) and A<sub>4</sub> (G) CMS systems were comparable for shoot fly resistance, while A<sub>1</sub> and A<sub>2</sub> were comparable for grain yield and grain mold resistance and were less susceptible to grain mold than the hybrids based on the A<sub>3</sub>, A<sub>4</sub> (M) and A<sub>4</sub> (G) CMS systems. Based on 45 SSR markers, seven pairs of lines with dissimilarity index of >0.50 and contrasting for resistance and susceptibility to grain mold were identified for developing mapping populations. Phenotyping of a mapping population for spotted stem borer resistance identified several traits that were associated with larval leaf feeding and dead heart formation. Morphological and chemical traits associated with shoot fly resistance were also identified. Minimum temperatures of 18–22°C during anthesis to fertilization, and maximum relative humidity during the hard dough stage to grain maturation appeared critical for infection and grain colonization by major grain mold pathogen species in the sorghum grain mold complex.

In pearl millet, nine A-lines of diverse morphological characteristics and genetic backgrounds in three diverse CMS systems (4 A<sub>1</sub>, 4 A<sub>4</sub> and 1 A<sub>5</sub>) with high levels of resistance to 2–5 diverse pathotypes of downy mildew (DM) were developed, designated and disseminated. Three B-lines of the A<sub>1</sub>-system A-lines are also maintainers of the A<sub>4</sub> CMS system. Similarly, nine morphologically and genetically diverse restorer lines (6 A<sub>1</sub>, 2 A<sub>4</sub>, and 1 dual-restorer of both A<sub>1</sub> and A<sub>4</sub>) with high levels of resistance to 2–5 diverse DM pathotypes were developed and designated. Marker-assisted introgression of QTL for DM resistance identified derivatives of three commercial seed parents that had high levels of resistance comparable to that of the donor parent. Strategic research targeted to arid zone showed that exploitation of heterosis for biomass yield alone or in combination with heterosis for harvest index is likely to be the most effective strategy for breeding high-yielding hybrids both for grain and stover yield. Based on AFLP analysis, 46 isolates of DM pathogen from seven states in India clustered into seven groups, with larger variability among the isolates within-states than among-states variability. Diversity analysis based on virulence index clustered these isolates into 8 groups. A preliminary research indicated that a bacterial strain of *Bacillus pumilus* (INR 7) could be as effective as metalaxyl in managing pearl millet downy mildew.

In pigeonpea, 16 medium-maturing hybrids with upto 62% grain yield advantage and maturity comparable to their respective controls (Asha and Maruti) were identified. In an experiment conducted to assess the effect of environment on male fertility restoration of A<sub>4</sub>-based hybrids, 32 hybrids were evaluated at four locations. Five of these hybrids had full fertility at Patancheru from where data had been received. A genetical study showed that, depending on the male parent involved in the cross, male fertility restoration of the A<sub>4</sub> CMS system was under the control of either a single dominant gene, or two genes with duplicate epistasis, or three genes with complementary epistasis.

## **I. Sorghum**

**Output target 5A.1: More than 35 parental lines of potential sorghum hybrids with high grain yield, and improved agronomic traits and biotic resistance developed (2007–2009)**

**Activity 5A.1.1: Develop and characterize a diverse range of improved parental lines**

*Milestone 5A.1.1.1: Ten male-sterile lines and five restorer lines with high yield and large grain developed (BVSR, 2007)*

**A/B-line development:** To diversify the hybrid parents for high grain yield, large grain and other preferred traits, diverse parents consisting of high-yielding B-lines and germplasm lines that belong to different races possessing useful traits were crossed. The resulting progenies were advanced with selection for desirable agronomic traits while maintaining desired maturity and grain yield. Promising F<sub>4</sub> progenies with maintainer reaction are being converted into A-lines with A<sub>1</sub> and A<sub>2</sub> CMS systems.

As a result, during the 2007 rainy season, 14 BC<sub>11</sub>s and 9 BC<sub>7</sub>s on A<sub>1</sub> cytoplasm and 11 BC<sub>11</sub>s and 7 BC<sub>6</sub>s on A<sub>2</sub> cytoplasm were selected for high yields and rainy season adaptation. For various other traits (grain luster and waxiness, pop sorghum, sweet stalk, leaf brown-midrib) and races (*Guinea*, *Feterita* and *Caudatum*), 12 BC<sub>7</sub>s and 17 BC<sub>6</sub>s on A<sub>1</sub> cytoplasm, and 7 BC<sub>8</sub>s, 23 BC<sub>7</sub>s and 3 BC<sub>6</sub>s on A<sub>2</sub> cytoplasm were selected. These will be further evaluated/ advanced during the 2007 postrainy season.

The B-lines converted into male-sterile lines that were completely stabilized and uniform were evaluated in replicated yield trials. The results are as under.

**Preliminary B-line trial (PBT):** Maintainers (B-lines) of 12 newly developed male-sterile lines with A<sub>1</sub> CMS system and 8 newly developed lines with A<sub>2</sub> CMS system were evaluated along with two checks in a preliminary B-line trial during the 2007 rainy season. Two B-lines of the A<sub>1</sub> CMS system – SP 54457-1 (5.4 t ha<sup>-1</sup> grain yield), SP 54421-1 (5.2 t ha<sup>-1</sup>) and one B-line with the A<sub>2</sub> CMS system – SP 54813-1 (5.3 t ha<sup>-1</sup>) were significantly superior to the check 296 B (3.6 t ha<sup>-1</sup>). The panicle grain mold rating (PGMR) recorded on a 1 to 5 scale (1= no grain mold infection and 5 = > 75% infection) showed that one B-line of the A<sub>1</sub> CMS system SP 54457-1 (3.0) and three B-lines of the A<sub>2</sub> CMS system SP 54817-1 (3.0), SP 54819-1 (3.0) and SP 54819-2 and SP 18845 (2.0) were superior compared to the susceptible check 296B (3.7).

**Advanced B-line trial (ABT):** An ABT consisting of 10 high-yielding B-lines selected from the evaluation of a preliminary B-line trial during the 2006 postrainy season and two checks was conducted during the 2007 rainy season. Six of the test B-lines, SP 1021, SP 1011, SP 1001, SP 1002, SP 1013 and SP 1012, with grain yield ranging from 3.5 to 5.0 t ha<sup>-1</sup> were significantly superior to the check 296B (2.2 t ha<sup>-1</sup>). Of these six B-lines, SP 1001 and SP 1002 (PGMR: 3), were significantly superior over the check 296 B (PGMR: 4.7) for resistance to grain mold.

**Elite B-line trial (EBT):** An EBT consisting of 17 high-yielding B-lines selected from the evaluation of Advanced B-line trial during the 2006 postrainy season and two checks was conducted during the 2007 rainy season. Five of the test B-lines, SP 1001, SP 1003, SP 1004, SP 1005 and SP 1018, with grain yield ranging from 4.8 to 5.2 t ha<sup>-1</sup> were significantly superior to the check 296B (3.5 t ha<sup>-1</sup>). Of these five B-lines, all except SP 1018 (PGMR score ranging from 2.3 to 3.0), were significantly superior over the check 296 B (PGMR: 4.0) for resistance to grain mold.

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*Milestone 5A.1.1.2: Five male-sterile lines resistant each to grain mold and shoot fly developed (BVSR/RPT/HCS/RS, 2008)*

**Grain mold resistance:** Grain mold is one of the major biotic constraints in sorghum during the rainy season. Efforts have been underway to develop new hybrid seed parents for grain mold resistance (GMR) as the available hybrid seed parents possess moderate resistance.

**Grain Mold Advanced B-line progenies Trial (GMABT):** GMABT consisting of 16 B-line progenies (8 BC<sub>6</sub>s, 2 BC<sub>5</sub>s and 4 BC<sub>3</sub>s on A<sub>1</sub> and 2 BC<sub>7</sub>s on A<sub>2</sub>) were screened along with three controls (296B-high yielding B-line, IS 14384-grain mold resistant line and Bulk Y-grain mold susceptible check) for grain mold tolerance in screening block and for grain yield evaluation in breeding block during the 2007 rainy season. In screening block, 296B recorded 87% panicle grain mold whereas IS 14384 and Bulk Y recorded 25% and 88%, respectively. All test entries recorded grain mold percentage ranging from 40 to 75%, compared to 87% in the popular B-line, 296B. Four BC<sub>6</sub>s progenies on A<sub>1</sub> were significantly better (43 to 52%) for grain mold tolerance and one progeny (SP 54853-3) among them was 14% significantly superior to 296B for grain yield in breeding block. These BC<sub>7</sub>s progenies will be further tested in the 2008 rainy season

**Grain Mold Hybrids and Parents Trial (GMHPT):** GMHPT consisting of nine hybrids along with their 12 parents (5 B-lines and 7 R-lines) and four controls (296B-high yielding B-line, CSH 16, NRCS-released commercial hybrid; IS 14384 grain mold resistant check; and Bulk Y, grain mold susceptible check) were screened for grain mold tolerance in screening block and grain yield evaluation in breeding block during the 2007 rainy season. In screening block, the resistant control IS 14384 had 8% grain mold whereas CSH 16 recorded 35% grain mold. All the hybrids in the trial recorded 7 to 27% grain mold indicating their superiority over CSH 16 (35% grain mold) for grain mold and two hybrids (4.0 and 4.5 t ha<sup>-1</sup>) were also significantly superior (>74%) to CSH 16 (2.4 t ha<sup>-1</sup>) for grain yield in breeding block. Among the seed parents, the B-lines

having 27–77% grain mold were significantly superior to 296B (90% grain mold). For grain yield, all the B-lines (except one) had 0.9–2.4 t ha<sup>-1</sup> grain mold, significantly superior (up to 140%) to 296B (0.9 t ha<sup>-1</sup>). The R-lines had 8–77% grain mold and two R-lines (PVK 801 and ICSV 96105) were on par with resistant control IS 14384 (8% grain mold) for grain mold reaction.

**Shoot Fly Advanced B-line progenies Trial (SFABT):** SFABT consisting of nine advanced B-line progenies (6 BC<sub>5</sub>S on A<sub>1</sub>; 2 BC<sub>7</sub>S and 1 BC<sub>5</sub>S on A<sub>2</sub>) were screened along with three controls (296B, high yielding B-line; IS 18551-shoot fly resistant control; and Swarna, shoot fly susceptible control) for shoot fly tolerance in screening block and shoot fly evaluation in breeding block during the 2007 rainy season. In screening block, 296B recorded 78% shoot fly deadhearts, whereas IS 18551 and Swarna recorded 40% and 67% shoot fly deadhearts, respectively. The progenies showed shoot fly deadhearts ranging from 30 to 84%, compared to the check 296B (78% deadhearts). Three BC<sub>5</sub>S progenies on A<sub>1</sub> were selected for rainy season adaptation with 12 to 55% superiority for shoot fly resistance and up to 50% superiority for grain yield over 296B (1.6 t ha<sup>-1</sup>) in breeding block. These progenies are further advanced in the 2007 post-rainy season for studying post-rainy season adaptation.

**Shoot Fly Hybrids and Parents Trial (SFHPT):** SFHPT consisting of 15 hybrids along with their parents (8 B-lines and 7 R-lines) and four controls (296B, high yielding B-line; CSH 16, NRCS-released commercial hybrid; IS 18551, shoot fly resistant check; and Swarna-shoot fly susceptible check) were screened in screening block for shoot fly resistance and for grain yield evaluation in breeding block during the 2007 rainy season. In screening block, the resistant control IS 18551 and CSH 16 showed 35% and 70% shoot fly deadhearts, respectively. All the hybrids recorded shoot fly deadhearts lesser than CSH 16, ranging from 22 to 64%. Eight hybrids were significantly superior (29 to 65% deadhearts) to CSH 16 for shoot fly resistance and one among them (ICSA 445 × ICSV 702) was on par with CSH 16 for grain yield (4.2 t ha<sup>-1</sup>) in breeding block. These eight hybrids will be further evaluated in the 2008 rainy season. All hybrid parents recorded shoot fly deadhearts (11 to 60%) lesser than 296B (82%). Four B-lines (ICSBs 438, 425, 444, and ICSB 433) were significantly superior by 38 to 72% to 296B for shoot fly resistance and by >15% for grain yield.

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Rajan Sharma and HC Sharma

**Genetic resistance to sorghum grain mold:** Grain mold is one of the most important biotic constraints to production of sorghum worldwide. The large-scale commercial cultivation of shorter-duration *kharif*-adapted white-grained hybrid sorghums has contributed significantly to enhanced grain productivity, but this has also led to increased grain mold problems. Developing grain mold resistant sorghum hybrids would provide the most economical disease management option to farmers. Identification of an improved level of grain mold resistance in advanced sorghum breeding lines and germplasm accessions has been a major focus towards developing grain mold resistant hybrids. Results of screening a number of sorghum lines against general mold fungi in a grain mold nursery are reported below.

**Grain mold resistance in hybrids and their parental lines:** Nine hybrids and 12 parental lines along with 1 resistant and 2 susceptible checks were evaluated for grain mold resistance. Sprinkler irrigation was provided twice a day for 30 min each on rain-free days starting from flowering to physiological maturity to provide high humidity (>90%RH) essential for mold development. The grain mold scores were recorded at physiological maturity (PM) using a 1 to 9 scale, where 1 = no mold infection and 9=75% moldy grains on a panicle. Four hybrids (ICSA 101 × PVK 801, ICSA 101 × IS 41675, ICSA 101 × GD 65028 and ICSA 382 × GD 65055) were found resistant (≤3.0 score) and the remaining hybrids exhibited moderate levels of resistance. Among parents, PVK 801 and ICSV 96105 were resistant and the other 9 were either susceptible or highly susceptible. Similarly, 84 alloplasmic isonuclear A/B lines and their hybrids were screened against grain mold. None showed resistance to pathogenic mold fungi.

**Sorghum grain mold resistance stability nursery (SGMRSN):** The SGMRSN is a collaborative nursery between ICRISAT and the All India Coordinated Sorghum Improvement Project (AICSIP), organized by ICRISAT under the ICAR-ICRISAT Partnership Project. The SGMRSN-2006 consisted of 50 entries including 22 B-lines, 10 R-lines, 12 lines from AICSIP, and 2 resistant (IS 25017 and IS 14384), one moderately resistant (PVK 801) and 2 susceptible (SPV 104 and Bulk Y) checks. The nursery was successfully established at Dharwad, Parbhani, Palem, Patancheru and Coimbatore. High relative humidity (>90% RH) essential for mold development was created by sprinkler irrigation at Patancheru. No artificial inoculation with any mold fungi was done. Five plants with uniform flowering in each row of the 2-row plot (10 plants plot<sup>-1</sup>) were tagged and the overall grain mold ratings of panicles were taken at physiological maturity (PM) on a progressive 1 to 5

scale (1 = no infection, 5 = >50% moldy grains on a panicle) The mean PGMR of 45 test entries across five locations varied from 1.3 (in ICSB 377) to 3.3 (in SGMR 3-3-5) compared to 1.0 to 2.2 in resistant checks and 4.2 in the susceptible checks, SPV 104 and Bulk Y. The mean PGMR score across entries was highest at Patancheru (3.5) followed by Palem (2.8), Coimbatore (2.7), Dharwad (1.7) and the lowest at Parbhani (1.2). Considering a rating scale of 1.1–2.0 (on a 1–5 scale) as resistant for the mean of PGMR, 11 of the 45 entries were resistant across the locations. Eleven entries (ICSB 355, -376, -377, -383, -388, GM 3, ICSB 355-1-10, -393-7-1, -401-4-2, -403-4-1 and SGMR 33-1-8-3-2) were identified as stable resistance sources across five locations.

RP Thakur, Rajan Sharma and BVS Reddy

**Evaluation of Sudangrass lines for resistance to sorghum downy mildew (*Peronosclerospora sorghi*):**

Sudangrass [*Sorghum bicolor ssp. sudanense*.] is well known for its fodder quality due to its rapid regeneration capacity, high tillering ability and high biomass productivity per unit of time and input. However, Sudangrass lines are generally known to be susceptible to sorghum downy mildew. The objective of this experiment was to identify sorghum downy mildew resistant Sudangrass lines that could be utilized in a breeding program to develop sorghum-Sudangrass forage hybrids with enhanced tillering and biomass productivity.

Ninety-three Sudangrass germplasm accessions originating from three countries (1 each from India and Italy, and 91 from USA) obtained from the ICRISAT genebank; one downy mildew resistant check sorghum line, QL 3; and one susceptible check line, 296B were screened using the sandwich technique under greenhouse conditions during July-August 2007. Each line was grown in 2 pots with 35–40 seedlings/pot. Downy mildew incidence was recorded 14 days after inoculation. The disease incidence varied from 11% in QL 3 to 100% in 296B and several others. None of the 93 test lines were disease-free. Among the test lines, IS 696 recorded the lowest incidence of 13%, while 82 lines showed >90–100% incidence. About 90 disease-free seedlings from six accessions (IS 696, -698, -699, -703, -3375 and IS 6014 with varied mean incidence of 13 to 77%) were selected and transplanted in pots for seed increase and further evaluation in the next generation to confirm the resistance. Downy mildew resistant progenies from these lines, if confirmed for high resistance levels, could be utilized in a sorghum-sudangrass hybrid breeding program.

RP Thakur, Rajan Sharma and BVS Reddy

**Grain mold resistance in maintainer progenies:** Sixteen advanced maintainer progenies, 137 F<sub>3</sub> progenies (from hard grain B-line, mold resistant B-lines and high yielding B-lines) and 23 F<sub>4</sub> (from landrace high yielding B-lines) along with 1 resistant and 2 susceptible checks were evaluated for grain mold resistance. Sprinkler irrigation was provided twice a day for 30 min each on rain-free days from flowering to physiological maturity to provide high humidity (>90%RH) essential for mold development. The grain mold scores were recorded at physiological maturity (PM) using a 1 to 9 scale. None of the progenies evaluated in this trial exhibited a high level of resistance. However, moderate resistance was observed in 2 F<sub>4</sub> (SP 55504-1 and SP 55504-2) and 11 F<sub>3</sub> progenies.

RP Thakur, Rajan Sharma and BVS Reddy

**Grain mold resistance in selections from B and R-lines, and germplasm lines:** Two hundred and seventy five grain mold resistant single-plant selections (from B and R-lines, and germplasm lines from the 2006 screen) along with resistant and susceptible checks were evaluated to confirm their resistance. The experiment was conducted under favorable conditions for mold development. Results indicated that 5 lines (IS 13756-5, IS 14384-1, IS 14384-2, IS 14387-1, and IS 14387-7) were highly resistant (score 1.0), 139 resistant (≤3.0 score), 72 moderately resistant (3.1–5.0 score) and the remaining 59 lines were susceptible or highly susceptible to grain mold.

RP Thakur and Rajan Sharma

*Milestone 5A.1.1.3: Five new high-yielding and large grain male-sterile lines in diverse backgrounds developed (BVSR/HDU, 2009)*

To diversify the hybrid parents in different backgrounds, diverse parents consisting of high-yielding B-lines and germplasm lines were crossed. The resulting progenies were advanced with selection for different traits while maintaining desired maturity and grain yield. Promising F<sub>4</sub> progenies with maintainer reaction are being converted into A-lines with A<sub>1</sub> and A<sub>2</sub> CMS systems.

As a result, during the 2007 rainy season, 4 BC<sub>3</sub>s, 15 BC<sub>4</sub>s and 177 BC<sub>1</sub>s on A<sub>1</sub> cytoplasm and 1 BC<sub>4</sub> on A<sub>2</sub> cytoplasm were selected for high grain yield and rainy season adaptation. For various other traits (grain luster, pop sorghum, sweet stalk and leaf brown-midrib), 13 BC<sub>5</sub>s and 6 BC<sub>4</sub>s on A<sub>1</sub> cytoplasm and 16 BC<sub>4</sub>s on A<sub>2</sub> cytoplasm were selected.

Testcrosses (TCs) of 634 F<sub>4</sub> and F<sub>5</sub> progenies were evaluated and simultaneously backcrossed onto A<sub>1</sub> CMS system. For bold grain and high yield, 160 BC<sub>1</sub>s and 109 F<sub>5</sub> and 19 F<sub>6</sub> progenies with R reaction were selected. These will be further advanced with selection during the 2007 postrainy season.

BVS Reddy, A Ashok Kumar and HD Upadhyaya

*Milestone 5A.1.1.4: Four new male-sterile lines resistant each to shoot fly and grain mold in diverse backgrounds developed (BVS/RPT/HCS, 2010)*

### **Shoot fly resistant male-sterile line development program**

**Shoot Fly Preliminary B-line progenies Trial (SFPBT):** SFPBT consisting of 14 advanced B-line progenies (5 BC<sub>3</sub>s, 1 BC<sub>2</sub>s and 8 BC<sub>1</sub>s) were screened along with three controls (296B, high yielding B-line; IS 18551, shoot fly resistant control; and Swarna, shoot fly susceptible control) for shoot fly tolerance in screening block and grain yield evaluation in breeding block during the 2007 rainy season. In screening block, 296B recorded 75% shoot fly deadhearts, where as IS 18551 and Swarna recorded 32% and 85% shoot fly deadhearts, respectively. The 13 progenies (except one BC<sub>2</sub> progeny - SP 63155-2) showed shoot fly deadhearts ranging from 31 to 72%, lesser than the 296B. Two BC<sub>3</sub> progenies were on par with the resistant control IS 18551. Four progenies significantly superior (29 to 50% deadhearts) for shoot fly resistance to 296B and more than 50% superiority for grain yield in breeding block were selected for rainy season adaptation. All these are under evaluation in 2<sup>nd</sup> 007 postrainy season for postrainy season adaptation.

We evaluated 85 F<sub>5</sub>s and 155 F<sub>7</sub>s for shoot fly resistance in screening block with three controls (IS 18551, shoot fly resistant control; Swarna, shoot fly susceptible control; and 296B, high yielding B-line) in 2007 rainy season. In F<sub>5</sub>s evaluation, IS 18551, Swarna and 296B showed 22%, 78% and 75% deadhearts respectively. The deadhearts in F<sub>5</sub>s ranged from 33 to 92% with an average of 65% (SE  $\pm$ 7.6) deadhearts. Fourteen F<sub>5</sub>s with deadhearts ranging from 33 to 48 and desirable agronomic traits were selected and advanced for further screening in the 2008 rainy season for rainy season adaptation. In F<sub>7</sub>s evaluation, IS 18551, Swarna and 296B showed 55%, 61% and 61% deadhearts, respectively. The deadhearts in F<sub>7</sub>s ranged from 39 to 93% with an average of 73% (SE  $\pm$ 7.1) deadhearts. Eleven F<sub>7</sub>s ranging from 39 to 55% deadhearts with desirable agronomic traits were selected and advanced for further screening in the 2008 rainy season with rainy season adaptation. The same set of 85 F<sub>5</sub>s and 155 F<sub>7</sub>s are under evaluation in the 2007 postrainy season for postrainy season adaptation.

Advanced 106 F<sub>4</sub>s derived from the crosses between shoot fly-resistant germplasm lines (new sources of resistance) and high-yielding established B-lines for further selection with shoot fly resistance in screening block with three controls (IS 18551, shoot fly resistant control; Swarna, shoot fly susceptible control; and 296B, high yielding B-line) in the 2007 rainy season. IS 18551, Swarna and 296B showed 25%, 85% and 75% deadhearts, respectively. The F<sub>4</sub>s had 30 to 92% deadhearts with an average of 68% (SE  $\pm$ 9.5) deadhearts. Sixteen F<sub>4</sub>s ranging from 30 to 50% deadhearts with desirable agronomic traits were selected and advanced for further screening in the 2008 rainy season for rainy season adaptation. The same set of 106 F<sub>4</sub>s are under evaluation in the 2007 postrainy season for postrainy season adaptation.

Conversion and evaluation of postrainy season adapted shoot fly resistant BC<sub>1</sub>s (141) and testcrosses (47) resulted in the selection of 34 BC<sub>2</sub>s and 8 BC<sub>1</sub>s on A<sub>1</sub> and 10 BC<sub>2</sub>s and 13 BC<sub>1</sub>s on A<sub>2</sub> for further conversion in the 2007 postrainy season.

Conversion and evaluation of rainy season adapted 47 BC<sub>1</sub> progenies (22 on A<sub>1</sub> and 25 on A<sub>2</sub>) derived from the crosses between shoot fly resistant maintainer lines and high-yielding breeding lines resulted in the selection of 3 BC<sub>2</sub>s on A<sub>1</sub> and 17 BC<sub>2</sub>s on A<sub>2</sub> for further conversion in the 2007 postrainy season.

Testcrosses (500) of the individual plants from four postrainy adapted shoot fly tolerant varieties are under evaluation in 2007 postrainy season for male-sterility/fertility reactions and back crossing with the maintainer progenies.

Advancing 133 BC<sub>1</sub>s on A<sub>1</sub> and 105 BC<sub>2</sub>s on A<sub>2</sub> obtained from F<sub>7</sub>s derived from the crosses between shoot fly-resistant B-lines and high yielding shoot fly resistant varieties and high-yielding established B-lines for grain lustere in the 2007 postrainy season

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*Milestone 5A.1.1.5: New male-sterile lines (4) introgressed with three selected shoot fly resistance QTLs in 296B and BTx 623 backgrounds completed (CTH/BVSR/HCS/SS, 2008)*

During the 2007 rainy season, we made the first crosses (to cytoplasmic male-sterile lines ATx623 and 296A) to initiate male-sterility conversion of the best available shoot fly resistance QTL introgression lines, producing the F<sub>1</sub> seed. Two additional generations of backcrossing, accompanied by marker-assisted selection in the A1-cytoplasm BC1F1 progenies, will be required to produce true-breeding A/B-pairs for each of the target shoot fly resistance QTLs in these two important seed parent maintainer genetic backgrounds. This conversion process should be completed during 2008 as we will be able to use SSR marker genotyping to identify BC1F1 individuals homozygous for the target QTL introgressions in the genetic background of a particular elite maintainer line (BTx623 or 296B) recurrent parent, and backcross these cytoplasmic male-sterile BC1F1 individuals to the appropriate near-isogenic QTL introgression line.

C Tom Hash and Santosh P Deshpande

### **Output target 5A.2: A diverse range of trait-specific sorghum breeding lines and populations with morphological diversity and resistance to shoot fly, stem borer and grain mold (2011)**

#### **Activity 5A.2.1: Generating new breeding lines with resistance to disease and insect pest resistance, and mapping of QTL and assessment of their effects on resistance levels for these traits**

*Milestone 5A.2.1.1: Forty sorghum F<sub>4</sub> lines developed for resistance to each of grain mold and shoot fly (BVSR/RPT/HCS/RS, 2008)*

Screened 138 F<sub>3</sub>s obtained from the crosses between hard grain B-lines, grain mold resistant B-lines, and high yielding B-lines for the development of grain mold resistant B-lines in the 2007 rainy season. Based on agronomic desirability and panicle grain mold (<50% grain mold), 97 F<sub>4</sub>s were selected for further screening in the 2008 rainy season. Forty-six F<sub>1</sub>s developed from crosses between shoot fly resistant RILs derived from the cross 296B × IS 18551 and high-yielding B-lines, shoot fly resistant B-lines, postrainy season varieties and shoot fly resistant germplasm lines were planted in the 2007 rainy season and 29 were advanced to F<sub>2</sub> for individual plant selection in 2007 postrainy season. Fifty-two F<sub>1</sub>s developed from crosses between shoot fly resistant progenies, Giddi Maldandi and high-yielding B-lines were planted in the 2007 rainy season and 35 were advanced to F<sub>2</sub> generation for individual plant selection in the 2007 postrainy season.

Twenty-three F<sub>2</sub>s developed from crosses between shoot fly resistant RILs derived from the cross 296B × IS 18551 and high yielding B-lines, shoot fly resistant B-lines, postrainy season varieties and shoot fly resistant germplasm lines were evaluated in the 2007 rainy season, producing 281 F<sub>3</sub>s with desirable yield potential and agronomic performance for further evaluation in the 2007 postrainy season.

BVS Reddy, A Ashok Kumar, RP Thakur,  
Rajan Sharma and HC Sharma

*Milestone 5A.2.1.2: Two F<sub>6</sub> RIL populations (300 lines each) developed for mapping grain mold resistance in sorghum (CTH/BVSR/SPD/RPT/RS, 2008)*

In addition, SSR-marker based diversity analysis was conducted for a new set of potential mapping population parental lines for sorghum grain mold resistance (see Milestone 5A.2.1.8 below) and seven parental line pairs were selected. Plant × plant crosses were made of these seven parental line pair combinations, and the putative F<sub>1</sub>s genotyped with a small number of SSRs (to confirm their hybridity and parentage)m and advanced by selfing to F<sub>2</sub> seed. Crosses of six of the seven combinations attempted were successful, and include brown × red, white × red, and white × white grain color combinations among the set of new grain mold resistance mapping populations that are being developed. Several F<sub>2</sub> populations were selected for generation advance to F<sub>3</sub> during the 2007/08 postrainy season.

CT Hash, SP Deshpande, RP Thakur and Rajan Sharma

*Milestone 5A.2.1.3: RIL for grain mold resistance from two mapping populations phenotyped and genotyped, and QTL maps developed using 300 markers (BVSR/CTH/SPD/RPT/RS, 2010)*

Two RIL F<sub>5</sub> populations (i) IS 23599 × AKMS 14B (350 RILs) and (ii) IS 25017 × KR 188 (350 RILs) and are under advancement to next generation (F<sub>6</sub>) in the 2007 postrainy season.

BVS Reddy, A Ashok Kumar, CT Hash,  
SP Deshpande, RP Thakur and Rajan Sharma

*Milestone 5A.2.1.4: Putative QTLs for stem borer resistance and its components based on RIL populations from two crosses identified (HCS/CTH/SPD, 2009).*

#### **Evaluation of mapping population for resistance to spotted stem borer, *Chilo partellus***

To identify molecular markers associated with resistance to spotted stem borer, *Chilo partellus*, the mapping population based on ICSV 745 × PB 15220 was evaluated for stem borer resistance under artificial infestation in the field as a part of the thesis research. The mapping population (270 lines), along with the resistant (IS 2205) and susceptible checks (ICSV 1), and the parents (PB 15220 and ICSV 745) were planted in a balanced alpha design, in three replications. Data were recorded on leaf feeding (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), deadheart formation (%), leaf glossiness (1 = highly glossy, and 5 = non-glossy), leaf sheath and plumule pigmentation (1 = highly pigmented, and 5 = Non-pigmented – green colored), stem tunneling (%), days to panicle initiation, recovery resistance (1 = good recovery, 5 = poor), and agronomic score (1 = good, and 5 = poor). There was a significant variation in the traits studied in the mapping population. Leaf damage rating (DR) was 5.52 in the PB 15220 and 7.84 in ICSV 745 compared to 4.47 in the resistant check, IS 2205 and 7.97 in the susceptible check, ICSV 1. The RIL population mean was 6.5. Deadheart formation was 71.6% in PB 15220 and 80.7% in ICSV 745 compared to 46.2% in the resistant check - IS 2205, and 66.3% in the susceptible check ICSV 1. Leaf glossiness score was 4.61 in PB 15220 and 4.37 in ICSV 745 compared to 2.1 of the resistant check - IS 2205, and 3.7 of the susceptible check ICSV 1. Over all resistance score was 5.7 in the PB 15220 and 7.7 in ICSV 745 compared to 4.2 in the resistant check, IS 2205 and 5.5 in the susceptible check, ICSV 1. Deadheart formation was significantly and negatively associated with agronomic score, leaf glossiness, overall resistance score, and recovery resistance. Leaf feeding was positively associated with overall resistance and recovery scores, but negatively associated with leaf angle, seedling pigmentation, and agronomic scores.

HC Sharma, CT Hash and SP Deshpande

*Milestone 5A.2.1.5: Comparative mapping of QTL for stem borer resistance in sorghum and maize completed (HCS/SPD/DH/CTH, 2009)*

Working toward this milestone in 2007 we made 61 plant-by-plant crosses between nine pairs of sorghum inbred lines previously demonstrated to differ in their stem borer resistance, and advanced several of these crosses to F<sub>2</sub> seed. First, during the 2006/07 postrainy season, we made line × line crosses (including reciprocals) of the following pairs in which the first-listed parent is stem borer resistant and the second is stem borer susceptible: ICSV 700 and ICSV 1, and IS 2205 and ICSV 1. During the 2007 rainy season, one plant-by-plant cross of each of four of the possible combinations (including reciprocals) between these two pairs of parental lines was advanced by selfing to produce single-plant-derived F<sub>2</sub> populations. These four F<sub>2</sub> populations will be advanced by two selfing generations during 2008.

In addition to the above crosses, we also produced plant-by-plant crosses between pairs of lines differing in their resistance to sorghum midge, including ICSV 700 and ICSV 745, IS 2205 and ICSV 745, ICSV 700 and AF 28, and IS 2205 and AF 28, in which the first-listed parent is stem borer resistant but midge susceptible, and the second parent is stem borer susceptible but midge resistant. Seed of 47 plant-by-plant crosses (including F<sub>1</sub> seed as well as selfed seed of both parental plants) was harvested for future use in developing new sorghum mapping populations segregating for stem borer resistance and/or midge resistance.

CT Hash, SP Deshpande and HC Sharma

*Milestone 5A.2.1.6: Effectiveness of two best QTL for resistance to shoot fly in two genetic backgrounds demonstrated (CTH/SPD/SS/HCS/BVSR, 2007)*

Under this activity area in 2007 we conducted multi-locational screening during the rainy season and postrainy season of the shoot fly response of shoot fly resistance QTL introgressions from donor parent IS 18551 in the genetic backgrounds of agronomically elite shoot fly-sensitive seed parent maintainer lines BTx 623 and 296B. A total of 104 QTL introgression lines were screened at two locations (Patancheru and Rajendranagar) in replicated late-rainy season and early postrainy season trials and nurseries. We are awaiting compilation of the



postrainy season screening data sets before compiling results; however, the following brief summary of Patancheru rainy season results is possible.

64-entry trial (32 test entries in BTx 623 background and 32 controls) evaluated as 2-row plots of 4-m length in 4 replications:

Four single-plant BC3-derived selections homozygous for the SBI-10 QTL introgression (increasing both seedling glossiness and trichome density) averaged 82% deadhearts incidence 14 days after emergence (DAE), 96% plants with eggs 14 DAE, and a seedling glossiness score of 3.6 at 9 DAE, compared to values of 93% deadhearts, 98% plants with eggs, and a seedling glossiness score of 5.0 for shoot fly susceptible recurrent parent BTx623, and 68% deadhearts, 94% plants with eggs, and a seedling glossiness score of 1.1 for shoot fly resistance donor parent IS 18551. Thus this single shoot fly resistance QTL region on SBI-10 appears to control a substantial portion of the resistance available from donor parent IS 18551, and this portion of the shoot fly resistance from this donor parent should be relatively easy to manipulate in a marker-assisted breeding program.

20-entry trial (14 test entries in 296B background and 6 controls) evaluated as 2-row plots of 2-m length in 3 replications:

Four single-plant BC3-derived selections homozygous for the SBI-05 glossiness QTL introgression averaged had seedling glossiness scores 9 DAE of 1.4 to 2.1, compared with scores of 0.3 to 0.7 for donor parent IS 18551 and 4.0 to 4.1 for recurrent parent 296B, but at least three of the four lines showed no improvement in shoot fly deadhearts incidence compared to their moderately shoot fly susceptible recurrent parent 296B. This suggests that the SBI-05 glossiness QTL from donor parent IS 18551 may not be substantially involved in host plant resistance to sorghum shoot fly, and thus need not be a target for marker-assisted selection.

84-entry trial (72 test entries in 296B background and 3 controls repeated 4 times each) evaluated as 1-row plots of 2-m length in 2 replications:

No significant improvements in shoot fly resistance could be detected in this low-replication small-plot trial. Further seed multiplication of these entries is needed to permit testing in sufficiently large numbers of replications of larger plot trials before the quantitative differences between entries can be accurately estimated.

***Milestone 5A.2.1.7: Comparisons of lines with single-QTL introgressions and QTL pyramided in two genetic backgrounds for shoot fly resistance completed (HCS/BVSR/CTH/SPD, 2010)***

See report for milestone 5A.2.1.6 above.

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HC Sharma, and Belum VS Reddy

***Milestone 5A.2.1.8: RIL populations for grain mold developed (RS/RPT/CTH/BVSR, 2010) (New)***

**Identification of contrasting parents for grain mold:** In a greenhouse screen in 2006, four lines (ICSB 352-5, ICSB 402-3, ICSB 370-2 and ICSR 89013-2) were found resistant to *F. verticillioides*; three (ICSB 402-3, ICSB 402-1-2 and SGMR 40-1-2-3) to *C. lunata*; and five (ICSB 402-3, ICSB 402-1-2, IS 41397-3, SPV 462-3, SP 72519-1-3) to *A. alternata*. Of these, only one line (ICSB 402-3) was resistant to all three pathogens; four (ICSB 370-1-5, ICSV 96094-2, ICSR 89013-2 and ICSB 379-2) to both *F. verticillioides* and *A. alternata* and two (ICSB 402-1-2 and SGMR 40-1-2-3) to both *C. lunata* and *A. alternata*. Some of these lines were used in 2007 for polymorphism survey to identify genetically diverse parents for developing RILs.

**Polymorphism survey in the resistant and susceptible parents using SSR markers:** We identified 72 resistant and 20 susceptible germplasm and breeding lines to assess genetic diversity among these in order to identify parental pairs for development of mapping populations. Allelic variation at 46 SSR marker loci well distributed across sorghum genome was used to assess this genetic diversity. Of the 46 SSR markers, 45 were polymorphic revealing 2 (*Xtp320*) to 20 (*mSbCIR306*) alleles with an average of 7.4 alleles per locus. Genetic diversity among the sorghum accessions was quite high as indicated by polymorphic information content (PIC) and gene diversity values. The PIC values of 45 polymorphic SSR markers ranged from 0.02 to 0.90 with an average of 0.54. The gene diversity in the sorghum lines varied from 0.0 to 0.90 with an average score of 0.58 per SSR marker. Seven pairs of resistant and susceptible parent lines with dissimilarity indices >0.50 were selected for use in developing RIL mapping populations for mapping genomic regions contributing to sorghum grain mold resistance.

**Crossing diverse parents (R and S) for developing RILs:** Based on the genetic diversity studies, seven pairs of susceptible and resistant lines—Bulk Y and ICSB 377, IS 30469C1667-2 and SGMR 40-1-2-3, SP 2417 and IS 41397-3, SPV 104 and ICSV 96094-2, IS 18758C 710-3 and IS 25103, ICSB 370-2-9 and IS 8385, and ICSB 370-2-9 and IS 8219 were selected to develop mapping populations. The pairs were crossed to obtain F<sub>1</sub>s and the F<sub>1</sub>s are being advanced in the glasshouse to develop RIL mapping populations.

Rajan Sharma, RP Thakur, CT Hash and BVS Reddy

### **Output target 5A.3: Transgenics for stem borer resistance in sorghum developed and tested (2009)**

#### **Activity 5A.3.1. Developing and testing transgenic sorghums for stem borer resistance**

*Milestone 5A.3.1.1: Protocols for the genetic transformation of sorghum optimized and two transgenic lines for resistance to stem borer developed and tested in contained field trials (KKS/HCS/BVSR, 2009)*

(Reported under Project 6)

### **Output target 5A.4: Variation in sorghum grain mold pathogens and mycotoxin contamination risk assessed, insect–host genotype-natural enemy interactions studied, and mechanisms of resistance to insect pests identified (2010)**

#### **Activity 5A.4.1: Understanding host-pathogen-environment interaction in grain mold complex**

*Milestone 5A.4.1.1: Major grain mold pathogens in sorghum growing states in India identified and their distribution in relation to weather factors determined (RPT/RS, 2007)*

**Major grain mold pathogens.** A large number of fungi, both saprophytic and pathogenic have been reported to be associated with the sorghum grain mold complex. In order to find genetic resistance in sorghum lines it is important that fungi that are truly pathogenic and actively involved in host-pathogen interaction are identified and their relative frequency determined. Through an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002-2004 several pathogens consistently associated with grain mold were identified. The analysis of SGMVN data from these locations revealed that several species of *Fusarium*, *Curvularia lunata* and *Alternaria alternata* were generally more frequent and highly consistent than other fungi. Of more than 900 isolates of *Fusarium* obtained from grain samples from these locations, six species of *Fusarium* (*F. proliferatum*, *F. verticillioides*, *F. thapsinum*, *F. andiyazi*, *F. nygamai* and *F. sacchari*) were identified. Strains of some of these *Fusarium* species are known to produce fumonisins, a kind of mycotoxin that is hazardous to health.

**Influence of weather variables on occurrence of pathogenic mold fungi.** We studied the influence of weather variables, temperature (T) and relative humidity (RH), on the occurrence of major pathogenic fungi, such as *Fusarium* spp. *Curvularia lunata*, *Alternaria alternata* and *Phoma sorghina* associated with sorghum grain mold in India. The T and RH data, and frequency of mold fungi collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002-2004 was used for this study. Since minimum temperature (T<sub>min</sub>) and maximum temperature (R<sub>max</sub>) during flowering to physiological maturity are most critical for mold development, distribution of pathogenic fungi in relation to these weather variables was studied. It appears that T<sub>min</sub> 18–20°C and RH<sub>max</sub> around 80% favored *Curvularia* at Akola and Surat and higher RH<sub>max</sub> (around 90%) and almost same T<sub>min</sub> favored *Alternaria* and *Phoma* at Patancheru. However high T<sub>min</sub> seems to favor *Fusarium* as the fungus was predominant at Parbhani having T<sub>min</sub> around 22°C.

RP Thakur and Rajan Sharma

*Milestone 5A.4.1.2: Mycotoxin-producing isolates of Fusarium species associated with grain mold identified and characterized, and genetic resistance in relation to other major pathogens determined (RPT/BVSR/RS, 2009)*

Association of mycotoxin-producing *Fusarium* spp. with sorghum grain mold in field and/or in storage is important because mycotoxin-contaminated food and feed create health hazards for humans and cattle. Forty-seven cultures of *Fusarium* spp., obtained from moldy sorghum panicles at ICRISAT were studied for their speciation and fumonisins (FB1 & FB2) production potential. A preliminary morphological study at Medical

Research Council, South Africa, revealed 17 of these cultures as potential fumonisin producers and subsequently 14 of these were confirmed through a mating type study at Kansas State University, USA. These cultures were tentatively identified into six different species: *F. proliferatum*, *F. thapsinum*, *F. verticillioides*, *F. sacchari*, *F. nygamai* and *F. andiyazi*. In a collaborative study with Iowa State University, Ames, 12 of these isolates were assayed for fumonisins FB<sub>1</sub> & FB<sub>2</sub> production using high performance liquid chromatography. Of these, *F. proliferatum* isolates produced higher FB<sub>1</sub> (2.318–7.560 µg/g) and FB<sub>2</sub> (0–8.478 µg/g) than other isolates. Insignificant amount of FB<sub>2</sub> was detected in isolates of *F. sacchari*, *F. andiyazi* and *F. nygamai* and in some isolates of *F. thapsinum*. FB<sub>1</sub> detected in potato dextrose-agar (PDA) culture of *F. proliferatum* was high (10.850 µg g<sup>-1</sup>) compared to that of *F. verticillioides* with no FB<sub>1</sub> detected. These results on species identification and fumonisins production by *Fusarium* spp. involved in sorghum grain mold complex in India are an important addition to the available information on fumonisins production by *Fusarium* species. Based on colony growth characteristics on PDA, 682 cultures of *Fusarium* collected from five locations (Akola, Parbhani, Palem, Patancheru and Surat) in India were tentatively classified into six species with varying frequencies. The mean frequency of *F. proliferatum* across locations was 48%, followed by 33% for *F. thapsinum*, 9% for *F. verticillioides*, 5% for *F. andiyazi*, 2% for *F. sacchari* and 1% for *F. nygamai*. Both *F. sacchari* and *F. nygamai* were not detected in Parbhani and Patancheru isolates. Selected isolates from the above-mentioned 5 locations will be further analyzed through AFLP to identify toxigenic *Fusarium* spp. associated with grain mold in India.

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*Milestone 5A.4.1.3: Relative contributions of host and environmental factors in mold development assessed in sorghum (RPT/RS/BVSR, 2010)*

**Contribution of host factors in mold resistance.** Several host morphological traits, such as panicle type, glume coverage, glume color, grain color and grain hardness are known to contribute to grain mold resistance in sorghum. We conducted a field trial consisting of 50 diverse sorghum lines including grain mold susceptible (SPV 104) and resistant (IS 8545) checks. The experiment was conducted. The sprinkler irrigation was provided twice a day for 30 min each on rain-free days from flowering to physiological maturity to provide high humidity (>90% RH) essential for mold development. The grain mold scores were recorded at physiological maturity using a 1 to 9 scale, where 1 = no mold infection (highly resistant) and 9=75% molded grains on a panicle (highly susceptible). Data on morphological traits were also recorded at physiological maturity. Five panicles from each test line were harvested to study the grain hardness. The mean grain mold scores ranged from 1.4 to 9.0 in the test lines. Data on morphological traits will be correlated with the average grain mold severity scores of 50 sorghum lines to determine the relative contribution of different morphological traits in grain mold resistance.

**Role of phenolics in grain mold resistance.** Resistance to grain mold is a complex trait and several biochemical traits have been shown to be associated with resistance. Phenolic compounds in sorghum caryopses are reported to improve resistance to insects, fungi and other pathogens, and cultivars with high tannin content have been used as a source of mold resistance. We estimated Flavon-4-ols in seed samples of 6 susceptible (SGMR 3-3-5-6, PVK 801-4, IS 36469C 1187-1-2-9-8-2, SP 72521-2-6-6-6, SPV 104, Bulk Y) and 11 resistant (IS 12932-2, IS 13969-1, SGMR 24-5-1-2, SGMR 11-3-5-1, ICSB 377, IS 8219-1, SGMR 40-1-2-3, IS 41397-3, ICSB 402-3, ICSB 402-1-2, SPV 462-3) lines of sorghum to find out the likely association with mold resistance. Mean Flavon-4-ols values of grain mold resistant and susceptible sorghum lines were distinctly different from each other. More Flavon-4-ols got accumulated in the methanol and acidified methanol extracts of both moldy as well as non-moldy grains of resistant lines than in susceptible lines. Similarly, the range of Flavon-4-ols extracted both in methanol as well as acidified methanol was very large in the resistant lines, whereas it was very narrow for the susceptible lines. More Flavon-4-ols were detected in the colored grains than in the white grains. In most of the lines, moldy grains recorded more Flavon-4-ols than non-molded grains. Considerable increase in the Flavon-4-ols content in the methanol extract was also observed in the molded grains of a white-grain resistant line SPV 462-3. This indicates that expression levels of Flavon-4-ols in the biosynthetic pathway are enhanced in response to the pathogen attack. Therefore, concentration of Flavon-4-ols in the mature sorghum seed can give an indication about the expected reaction of the sorghum cultivars to grain mold and differential levels of Flavon-4-ols can be used as a biochemical marker for grain mold resistance. However, the results need further confirmation using susceptible and resistant lines following artificial inoculations under greenhouse conditions.

Influence of weather variables on grain mold development. We studied the influence of weather variables, temperature (T) and relative humidity (RH) on sorghum grain mold development. The T and RH data, and grain mold severity scores collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Resistance Stability

Nursery (SGMRSN) conducted at four locations (Coimbatore, Dharwad, Parbhani and Patancheru) for two rainy seasons 2005 and 2006 were used for this study. The weekly averages (across locations and seasons) of T (Tmax and Tmin) and RH (RHmax and RHmin) for a 2-month post-flowering period (grain-filling to physiological maturity period) were correlated with the average grain mold severity scores of 32 sorghum lines of the SGMRSN. Positive and significant correlations ( $r = 0.96$ ,  $P < 0.05$ ) were found between average weekly Tmin (18.5 to 22.5°C) during the standard 37<sup>th</sup> and 38<sup>th</sup> week (the 1<sup>st</sup> and 2<sup>nd</sup> weeks after panicle emergence) and the average grain mold severity of sorghum lines. This two-week period coincided with the anthesis and ovary fertilization stages of most sorghum lines during which time infection by mold pathogens took place. Similarly, significant positive correlation was found between the average RHmax (76 to 96%) during the standard 41<sup>st</sup> and 42<sup>nd</sup> week (the 5<sup>th</sup> and 6<sup>th</sup> week after panicle emergence) and the average grain mold severity ( $r = 0.87$ ,  $P < 0.05$ ). This period, for most sorghum lines, coincided with hard-dough to physiological maturity stages, and during this period infected grains, under high humidity conditions, showed rapid colonization by various mold fungi. Such infected grains developed growth of other saprophytic fungi as well when left in the field beyond physiological maturity. The regression analyses showed a near-linear relationship between Tmin and grain mold severity scores ( $R^2 = 0.96-0.99$ ), and between RHmax and grain mold severity scores ( $R^2 = 0.98-0.99$ ). Thus, the two most important weather variables, Tmin during anthesis to fertilization stage and RHmax during hard-dough to grain maturity stage appeared critical for infection and grain colonization by major mold pathogens (species of *Fusarium*, *Curvularia* and *Alternaria*) in the sorghum grain mold complex.

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#### **Activity 5A.4.2: Develop screening techniques and investigate host genotype - natural enemy interactions, resistance mechanisms and genetics of insect pest resistance**

*Milestone 5A.4.2.1: Insect – host genotype - natural enemy interactions, and mechanisms of resistance and their inheritance studied in sorghum (HCS/BVSR, 2009)*

**Multiple resistance to insect pests in sorghum:** To identify sorghum lines with resistance to different insect pests, and to understand the resistance mechanisms and diversity, germplasm and breeding lines that have been identified to be resistant to different insect pests (sorghum shoot fly - *Atherigona soccata*, spotted stem borer - *Chilo partellus*, sorghum midge - *Stenodiplosis sorghicola*, and head bugs - *Calocoris angustatus* and *Eurystylus oldi*) in the past 25 years were evaluated for resistance to shoot fly, stem borer, midge, and head bugs during the 2006/07 postrainy season. The lines showing resistance to individual pests were selected for further testing for resistance to all the four pests. The material was divided into early-duration and dwarf lines, medium-duration and medium height, and long-duration and tall height. There were 53 lines in the short-duration group, 113 in medium-duration, and 104 in the long-duration group, including the resistant and susceptible checks. The test material was planted in 2 row plots, 2 m long, and there were two replications in a randomized complete block design. Data were recorded on leaf glossy score (1 = glossy, and 5 = non-glossy), shoot fly deadhearts (%), recovery resistance and overall resistance scores (1 = good, and 5 = poor), and agronomic performance (1 = good, and 5 = poor) in the shoot fly nursery. For stem borer resistance, the data were recorded on leaf feeding (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), deadheart formation (%), recovery and overall resistance scores (1 = good, and 5 = poor), and agronomic desirability (1 = good, and 5 = poor). In the midge nursery, the material was evaluated for midge resistance on a 1– 9 scale (1 = <10 spikelets damaged by midge, and 9 = >80% spikelets damaged by midge). Data were also recorded on days to 50% flowering and plant height.

In the shoot fly short-duration nursery, the genotypes ICSV 25006, ICSV 25017, ICSV 25019, ICSV 25026, ICSV 25180, ICSV 25006, and PS 37662-2 showed combined high to moderate levels of resistance to shoot fly and sorghum midge; while in the medium-duration nursery, ICSV 25004, ICSV 707, ICSV 25006, ICSV 89010, IS 10712, IS 2122, and IS 5470 showed combined resistance to shoot fly and sorghum midge. In the long-duration nursery, IS 2123 and IS 9807 suffered moderate levels of damage by these insects, suggesting that most of the long-duration lines either have resistance to shoot fly or to sorghum midge, but have little tolerance to both. In the stem borer screening under artificial infestation, the genotypes ICSV 25026, ICSV 25138, ICSV 564, ICSV 93009, and IS 2205 suffered low to moderate levels of leaf feeding and deadheart formation in the short duration nursery. These lines also showed good recovery resistance following stem borer infestation. In the medium-duration nursery, ICSV 25092, ICSV 25118, ICSV 702, ICSV 717, ICSV 89057, ICSV 93011, IS 12308, IS 18368, IS 18569, IS 2376, IS 4546, IS 4757, IS 4995, IS 5470, IS 5480, IS 5619 combined resistance to leaf feeding, deadheart formation and recovery resistance for Stem borer, *C. partellus* damage. In the long-duration group, 25 lines showed resistance to leaf feeding and deadheart formation, and these lines also exhibited good recovery resistance. The results suggested that long-duration lines are more resistant to stem

borer, but are susceptible to damage by sorghum midge, *S. sorghicola*. In the midge screening short-duration nursery, ICSV 197, ICSV 25183, ICSV 25183, ICSV 93009, ICSV 25183, and ICSV 96011 showed combined resistance to sorghum midge and sugarcane aphid, and were also superior agronomically. In the medium-duration trial, 26 lines showed combined resistance to sorghum midge and sugarcane aphid, and had good agronomic desirability, while in the long-duration trial, only five lines showed combined resistance to these pests, but were poor agronomically.

HC Sharma

**Physico-chemical mechanisms of resistance to sorghum shoot fly, *Atherigona soccata*:** We evaluated a diverse array of 15 sorghum genotypes to identify physico-chemical characteristics of the host plant conferring shoot fly resistance. The material was evaluated for resistance to shoot fly under field conditions. Data were also recorded on physico-chemical characteristics of the test genotypes. Genotypes with non-glossy leaves, and non-pigmented (green) leaf sheath and plumule, and having high amounts of soluble sugars and fats, and high seedling vigor were susceptible to shoot fly; while those with greater plant height and trichome density, and high tannin, Mg, and Zn contents showed resistance to shoot fly. The productive tillers, total proteins, N, K, and Ca were correlated positively; while polyphenols, lignins, P, Mn, Cu, and Fe were correlated negatively with susceptibility to shoot fly. Multiple linear and stepwise regression indicated that Mg, Zn, soluble sugars, tannins, fats, leaf glossiness, leaf sheath and plumule pigmentation, and trichome density explained 99.8% variability for deadhearts produced by shoot fly damage. Path coefficient analysis revealed that leaf glossiness, plumule pigmentation, trichomes, and fat content had direct effects and correlation coefficients for deadhearts in the same direction, and these traits can be used to select for shoot fly resistance; while leaf pigmentation and tannins though highly correlated with resistance/susceptibility of shoot fly, their direct effects were in the opposite direction. Principal component analysis indicated that there was a considerable genetic diversity among genotypes showing resistance and susceptibility. Genotypes placed in different groups and with different combination of traits associated with shoot fly resistance can be used to increase the levels and diversify the genetic bases for resistance to shoot fly in sorghum.

HC Sharma

*Milestone 5A.4.2.2: Techniques to evaluate sorghums for resistance to sugarcane aphid and shoot bug developed, and sources of resistance identified in sorghum (HCS, 2009).*

**Identification of sources of resistance to sugarcane aphid, *Melanaphis sacchari*:** Thirty-five sorghum lines comprising improved breeding lines and germplasm accessions were screened for resistance to sugarcane aphid during the 2006/07 post-rainy season. There were three replications in a RCBD, and observations were recorded at physiological maturity on aphid damage (1 = <10% leaf area damaged, and 9 = >80% leaf area with aphid damage). Aphid damage scores ranged from 2.0 to 8.3, and the lines 61523, 61581, 61582, 61588, 61592, 61602, IS 40615, and IS 40616 suffered aphid damage rating of <3.0 compared to 2.7 in the resistant check, TAM 428, and 8.3 in the susceptible check, Swarna.

In the cooperative trial with the All India Coordinated Sorghum Improvement Project, 48 lines were screened for resistance to sugarcane aphid under natural field conditions. The material was evaluated for aphid damage at physiological maturity. SLR 8, SLR 27, SLR 31, SLR 35, SLR 39, SLR 41, SLV 25, IS 3420, and PU 10-1 suffered an aphid damage rating of <4.0 compared to 3.3 in the resistant check, TAM 428, and 9.0 in the susceptible check, Swarna.

Twenty-eight sorghum lines comprising improved breeding lines and germplasm accessions were screened for resistance to sugarcane aphid during the 2007 rainy season. There were three replications in a RCBD, and observations were recorded at physiological maturity on aphid damage on a 1–9 scale as described above. Aphid damage scores ranged from 3.0 to 8.0, and the lines 61581, 61588, 61592, and DJ 6514 showed an aphid damage rating of <4.0 compared to 5.5 of the resistant check, TAM 428, and 8.0 in the susceptible check, Swarna.

Nine genotypes along with the susceptible check, Swarna were also evaluated for resistance to *M. sacchari* under greenhouse conditions using artificial infestation, and under laboratory conditions using detached leaf assay. Under greenhouse conditions, artificial infestation of the test material with aphid infested leaves from the field resulted in very high infestation by the sugarcane aphid. However, the trial entries could not be evaluated for aphid damage because of heavy shoot bug, *Peregrinus maidis*, infestation. Under laboratory conditions, the test material was evaluated using detached leaf assay. Fifteen cm leaf discs from the middle portion of 5<sup>th</sup> leaf were inserted in 3% agar-agar in a 1 L plastic jar. Each leaf was infested with 10 gravid females. Numbers of

aphids were counted 7 days after infestation. Aphid numbers varied from 19.8 on CK 60B to 168 aphids on Swarna. Aphid multiplication was lower on CK 60B, IS 21870, IS 40615, IS 40616, and IS 40618 (<90 aphids) compared to that on Swarna (168 aphids). These experiments will be repeated in the coming seasons to refine the screening technique.

HC Sharma and VR Bhagwat

## **Output target 5A.5: Information on association between CMS and agronomic traits, and between molecular diversity and yield heterosis in sorghum (2009)**

### **Activity 5A.5.1: Evaluation of iso-cytoplasmic hybrids for grain yield and agronomic traits**

*Milestone 5A.5.1.1: Twelve hybrids with four diverse CMS systems compared for agronomic traits and resistance to shoot fly and grain mold (BVS/RPT/RS/HCS, 2009)*

The need for cytoplasmic diversification of A-lines (and hybrids) to avert the potential risk of unforeseen disease and insect pest outbreaks associated with cytoplasmic uniformity is common knowledge. Cytoplasmic diversification also enhances the opportunities for diversifying the nuclear genetic base of A-lines as some of the outstanding restorers on one cytoplasm are found to be maintainers of other cytoplasm. However, in pursuit of diversifying the CMS base of hybrid seed parents and hence the hybrids, the performance of hybrid seed parents and the hybrids based on alternative CMS systems for grain yield and other agronomic traits and plant defensive traits of economic importance cannot be compromised. An investigation was, therefore, carried out to assess the efficiency of A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub> CMS system in comparison to the widely used A CMS system.

Isonuclear alloplasmic A-lines with A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub> and A<sub>4</sub> (G), A<sub>4</sub> (M) and A<sub>4</sub> (VZM) cytoplasm each in six nuclear genetic backgrounds (ICSB 11, ICSB 37, ICSB 38, ICSB 42, ICSBA 88001 and ICSB 88004) were crossed with two common R-lines (IS 33844-5 and M35-1-19) to generate 72 hybrids in the 2005 postrainy season. These 72 hybrids were evaluated for grain yield and other traits during the 2006 postrainy and 2007 rainy season in split-a-split-plot design with three replications considering R-lines as main plots, genetic backgrounds of A-lines as sub-plots and cytoplasm as sub-sub-plots. The 6 B-lines and 4 checks (296B, RS 29, CSH 16 and CSV 15) were evaluated in a separate trial using randomized complete block design with three replications. Same set of hybrids and their parents were screened for grain mold (2007 rainy season) and shoot fly (2006 postrainy and 2007 rainy season) in screening blocks.

### **CMS effect on grain yield and other agronomic traits**

**Postrainy season adaptation:** There were significant differences among female parents irrespective of background cytoplasm for plant height, fertility restoration, 100-grain weight and grain yield; and among the male parents for days to 50% flowering, plant height and fertility restoration. Similarly, non-significant mean squares due to A × R-line interaction indicated that hybrids did not differ significantly for their *sca* effects for any of the traits except fertility restoration. Cytoplasm *per se* appeared to have significant influence on the expression of hybrids for restoration and grain yield. It is important to note that first-order interaction of cytoplasm with nuclear genetic background of A-lines (for all traits except 100-grain weight) or R-lines (for restoration) and second-order interaction with A-line and R-lines (for plant height, restoration and grain yield) towards variation of iso-nuclear hybrids was significant, suggesting significant but variable influence of cytoplasm, depending on the genetic background.

The comparison of A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub> (M), A<sub>4</sub> (G) and A<sub>4</sub> (VZM) cytoplasm-based hybrids indicated that A<sub>1</sub> and A<sub>2</sub> cytoplasm-based crosses were significantly earlier to flower compared to those based on A<sub>3</sub> cytoplasm. A<sub>1</sub> and A<sub>2</sub> cytoplasm-based hybrids though on par with each other and showed significantly greater restoration than A<sub>3</sub>, A<sub>4</sub> (M), A<sub>4</sub> (G) and A<sub>4</sub> (VZM) cytoplasm-based hybrids. The order of restoration was A<sub>1</sub>>A<sub>2</sub>>A<sub>4</sub>(M)>A<sub>3</sub>>A<sub>4</sub>(VZM)>A<sub>4</sub>(G). A<sub>1</sub> and A<sub>2</sub> cytoplasm-based hybrids were significantly superior to A<sub>3</sub>, A<sub>4</sub> (G) and A<sub>4</sub> (VZM) cytoplasm-based hybrids (by 0.9 to 1.4 t ha<sup>-1</sup>) for grain yield.

Thus, the comparable grain yield potential of A<sub>1</sub>, A<sub>2</sub>, A<sub>4</sub> (M) cytoplasm-based hybrids in similar maturity and plant height backgrounds suggests the usefulness of A<sub>2</sub> and A<sub>4</sub> (M), cytoplasm for diversifying the cytoplasmic and nuclear genetic base of sorghum hybrid parents.

**Grain mold resistance:** A total of 84 entries including 72 hybrids, 8 parents and 4 checks were screened for grain mold resistance during the 2007 rainy season. Sprinkler irrigation was provided for 30 min per day on dry

days during flowering to physiological maturity of the crop to create high humidity (>90% relative humidity), congenial for the development of adequate and uniform disease pressure. Ten panicles of uniformly flowering plants were tagged in each replication for recording panicle grain mold score (PGMR) at physiological maturity using a 1-9 progressive scale where 1 = no mold, 2 = 1-5%, 3 = 6-10%, 4 = 11-20%, 5 = 21-30%, 6 = 31-40%, 7 = 41-50%, 8 = 51-75% and 9 = >75% mold. There were significant differences amongst cytoplasm *per se* for PGMR. The significant mean squares due to interaction of cytoplasm (with A-line genotype) and R-lines and A × R-lines interaction suggested that the effect of cytoplasm was significantly influenced by the genetic backgrounds of both female and male parents.

The comparison of A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub> (M), A<sub>4</sub> (G) and A<sub>4</sub> (VZM) cytoplasm-based hybrids indicated that A<sub>1</sub> cytoplasm-based hybrids were on par with A<sub>2</sub>-based hybrids, and were less susceptible to grain mold compared to A<sub>3</sub>, A<sub>4</sub>(M), A<sub>4</sub>(G) and A<sub>4</sub>(VZM) cytoplasm-based hybrids. A<sub>4</sub> (VZM) cytoplasm-based hybrids were less susceptible than A<sub>3</sub>, A<sub>4</sub>(M) and A<sub>4</sub>(G) based hybrids. However, when mean PGMR scores of different cytoplasm-based hybrids were examined, there were seldom any differences in their responses to grain mold.

**Shoot fly resistance (Rainy season adaptation):** From the trial evaluated during the 2007 rainy season, it was evident that there were significant differences amongst A-lines (nuclear genotype) for shoot fly deadheart suggesting considerable differences among the seed parents for responses to shoot fly. Non-significant mean squares due to cytoplasm *per se* and interaction of cytoplasm with A-lines and R-lines and A × R-lines interaction for deadheart indicated that cytoplasm did not have significant influence on responses to shoot fly and was therefore the effect of its interaction with the genetic backgrounds of both female and male parents.

The comparison of A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub>(M), A<sub>4</sub>(G) and A<sub>4</sub>(VZM) cytoplasm-based hybrids indicated that A<sub>1</sub>, A<sub>3</sub>, A<sub>4</sub>(M), A<sub>4</sub>(G) and A<sub>4</sub>(VZM) cytoplasm-based hybrids were comparable for resistance to shoot fly. However, A<sub>4</sub>(M) and A<sub>4</sub>(G) cytoplasm were superior to A<sub>2</sub> cytoplasm for shoot fly. Yet, when mean deadheart of different cytoplasm-based hybrids was examined, there were seldom any differences in their responses to shoot fly.

**Shoot fly resistance (Postrainy season adaptation):** From the trial results during the 2006 postrainy season, the non-significant mean squares due to cytoplasm *per se* and interaction of cytoplasm with A-lines and R-lines and A × R-lines interaction for deadheart indicated that cytoplasm did not have significant influence on resistance to shoot fly.

The comparison of A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub>(M), A<sub>4</sub>(G) and A<sub>4</sub>(VZM) cytoplasm-based hybrids indicated that A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, A<sub>4</sub>(M), A<sub>4</sub>(G) and A<sub>4</sub>(VZM) cytoplasm-based hybrids were comparable for resistance to shoot fly. No particular cytoplasm seemed to influence resistance to shoot fly during the postrainy season.

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### **Activity 5A.5.2: Assessing the relationship between molecular diversity of parental and yield heterosis**

*Milestone 5A.5.2.1: Relationship between parental molecular diversity and hybrid heterosis assessed in sorghum (CTH/SPD/BVSR, 2009)*

The sorghum program at ICRISAT-Patancheru over the years has developed a large number of trait-based hybrid parents including more than 600 A-/B-lines and more than 800 R-lines, which has substantially contributed to the hybrid development by private sector and NARS partners in India and other countries. It is imperative to characterize them as per the descriptors in DUS (Distinctness, Uniformity, Stability) test guidelines to keep them in the public domain and prevent others taking IP protection. In this direction, 269 A-/B-lines and 156 R-lines (Set I); and 156 B-lines and 171 R-lines (Set II) were characterized using 41 descriptors in DUS test guidelines, plus 5 ancillary characters and the date were published in International Sorghum and Millets Newsletter (ISMN) Special issues in 2006 (Set I) and 2007 (Set II). The ISMN special issues and CDs containing all this information along with the photographs were widely circulated. This information is uploaded on the ICRISAT website. The characterization of remaining hybrid parents is completed and will be published in 2008. As per the UPOV guidelines, this characterization will suffice to make this information in the public domain, and will thus prevent others from taking IP rights on these materials.

The molecular characterization (fingerprinting) serves as ancillary data and also prevents others from taking IP protection on this material. It helps in understanding the diversity in the hybrid parents at molecular level that enables the breeder to develop a heterotic gene pool and more heterotic hybrids. Also, it is possible to correlate

the morphological and molecular diversity with heterosis for grain and stover yields. In this direction, a total of 140 B-lines and 140 R-lines were sown in the glasshouse and genomic DNA was isolated from the young leaves. Genotyping of these lines with 30 SSR markers is in progress. Once genotyping is done, these lines will be assessed for molecular diversity.

Ten each of B- and R-lines were planted during the 2007 rainy season and 40 selfed plants were randomly selected from each line and harvested separately. These will be planted individually during the 2008 postrainy season for DNA fingerprinting and morphological characterization to determine within-line diversity

Marker genotyping across 16 of 39 SSR loci used for diversity analysis of sorghum was completed for 188 sorghum hybrid parents of ICRISAT-Patancheru origin, including 94 B-lines and 94 R-lines, along with reference genotypes 296B and BTx623. Using the DARwin software package, a simple matching dissimilarity index was calculated from the allele-size data set, and this matrix was then subjected to Neighbor-Joining analysis and factorial analysis. The second axis of the principal components analysis largely separated the B-lines from the R-lines. Cluster analysis identified three major groups of sorghum hybrid parental lines, each of which contained both B- and R-lines. Several subclusters within each of the three main clusters were comprised largely of B-lines or largely of R-lines. Based on this initial marker-based diversity assessment, parents to be crossed to produce hybrids to test the relationship between hybrid performance/heterosis and marker-based genetic distance between the parental lines of the hybrid, were chosen.

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#### **Output target 5A.6: High-yielding and good combining sorghum hybrid parents developed for postrainy season adaptation (2009)**

##### **Activity 5A.6.1: Developing high-yielding and good combining sorghum hybrid parents for postrainy season adaptation**

*Milestone 5A.6.1.1: Five each of high-yielding and good combining sorghum male-sterile lines and restorer lines for postrainy season developed (BVSR, 2009)*

Postrainy season sorghum produces high quality grain for human consumption in India. The bold, white seed with lustre fetches a bigger price in the market. There are no hybrids available in the market with high yields and acceptable quality. There is an urgent necessity to breed postrainy season-adapted hybrid parents with high grain and stover yields with acceptable quality.

Several early-maturing advanced generation progenies derived from the crosses between postrainy season-adapted varieties, high-yielding B-lines and landraces were evaluated during the 2005 postrainy season.

**Hybrids demonstration and R-line development:** During the 2006 late postrainy season, 101 hybrids were generated involving postrainy season adapted B-lines (23) and R-lines (16). These are being evaluated during the 2007 postrainy season along with the checks, SPH 840 and SPV 1411. From the variety  $\times$  variety crosses, a total of 90 F<sub>6</sub>s, 125 F<sub>4</sub>s and 299 F<sub>3</sub>s were selected for high grain yield, grain luster and postrainy season adaptation. From the crosses made between postrainy season-adapted dual-restorers of A<sub>1</sub> and A<sub>2</sub> (M 35-1-19, ICSR 93001, ICSR 92003, ICSR 93031 and IS 33844-5), 21 F<sub>3</sub>s were selected from 18 F<sub>2</sub>s. From 40 F<sub>1</sub>s made between lustrous germplasm lines and M 35-1 Tan selections, M 35-1 variety and postrainy season-adapted R-lines, 36 plants were selected during the 2007 rainy season. From the 21 F<sub>1</sub>s made between bold grain F<sub>2</sub>s and postrainy season adapted varieties, 10 F<sub>2</sub>s were selected during the 2007 rainy season.

**B-line development:** From 469 Giddi Maldandi-based testcrosses, two BC<sub>1</sub>s (A<sub>1</sub> CMS system) were obtained and they will be further converted into male-sterile lines. From 124 B R F<sub>7</sub> progenies, 37 F<sub>8</sub> progenies were selected and evaluated along with their testcrosses (TCs) during the 2007 rainy season. Of these, 7 were selected and backcrossed to develop BC<sub>1</sub> progenies. Of 426 B R F<sub>5</sub> progenies, 153 F<sub>6</sub> progenies were selected and evaluated along with their TCs during the 2007 rainy season. Of these, 26 were selected and backcrossed to develop BC<sub>1</sub>s. All these will be further used for backcrossing during the 2007 postrainy season for conversion into A-lines. Of 63 B R F<sub>4</sub> progenies, 72 F<sub>5</sub> progenies were selected and evaluated along with their TCs during 2007 rainy season. Of 78 F<sub>4</sub>s derived from the crosses between Giddi Maldandi high yielding B-lines, 82 F<sub>5</sub> progenies were selected and evaluated along with their TCs during the 2007 rainy season. Of these, 66 R-lines



that showed restorer reaction were selected to be included in R-line development program. From the 370 F<sub>2</sub>s derived from the B × R crosses for postrainy season adaptation, 682 F<sub>3</sub>s were produced during the 2006 postrainy season and they are being further advanced with selection during the 2007 postrainy season. Lustrous germplasm lines were crossed with maintainer progenies and 639 F<sub>3</sub>s were obtained from 183 F<sub>2</sub>s with selection for bold grain, high yield and postrainy plant type. They are being further advanced during the 2007 postrainy season.

Of the 38 F<sub>1</sub>s made between bold grain germplasm lines and dwarf and bold grain B-lines, 26 were selected and F<sub>2</sub>s were produced during the 2007 rainy season. Of the 31 F<sub>1</sub>s made between dwarf B-lines and postrainy season adapted varieties, 30 F<sub>2</sub>s were produced during the 2007 rainy season.

**Postrainy B-population:** Giddi Maldandi F<sub>4</sub> bulk was introgressed into postrainy B-population bulk (R1) during the 2007 rainy season. From the population bulk, 196 dwarf steriles with moderate to bold grain size and from Giddi Maldandi F<sub>4</sub> bulk, 67 fertiles were harvested. These were planted along with M 35-1 derivatives bulk and dwarf B-lines postrainy varieties bulk during the 2007 postrainy season for the development of postrainy season adapted B-population.

### **Output target 5A.7: High-yielding dual-purpose foliar disease resistant forage/ sweet sorghum hybrid parents (2009)**

#### **Activity 5A.7.1: Developing dual-purpose foliar disease resistant forage/sweet sorghum hybrid parents**

*Milestone 5A.7.1.1: Six new dual-purpose foliar disease resistant forage/sweet sorghum hybrid parents developed (BVSR, 2009)*

High-yielding designated hybrid parents with sweet stalk, and varieties and hybrids developed by crossing promising sweet sorghum A- and R-lines were evaluated in replicated trials during the 2006 postrainy and 2007 rainy seasons. Results of these trials are given below.

**E 36-1-based sweet sorghum preliminary hybrid trial (E 36-1 SSPHT, 2006R):** Sweet sorghum B-lines were crossed with E 36-1 (stay-green variety) to generate 14 hybrids and these were evaluated along with the checks ICSSH 8 (ICRISAT-developed sweet sorghum hybrid tested in AICSIP) and NSSH 104 (the sweet sorghum hybrid developed by Indian national program using an ICRISAT B-line). The hybrid ICSA 474 × E 36-1 (1.5 t ha<sup>-1</sup>) was significantly superior to the check NSSH 104 (0.9 t ha<sup>-1</sup>) for sugar yield while the other 10 hybrids with 0.4 to 1.4 t ha<sup>-1</sup> sugar yield were comparable to the check. Of these, 11 high sugar yield hybrids, ICSA 24005 × E 36-1 (7.9 t ha<sup>-1</sup> sugar yield) were comparable to the check NSSH 104 (9.9 t ha<sup>-1</sup> sugar yield) for grain yield. The restoration in the hybrids ranged from 0 to 100% with 10 hybrids recording restoration below 20%. However, compared to the check ICSSH 8 (1.4 t ha<sup>-1</sup>), 6 hybrids with a sugar yield of 1.0 t ha<sup>-1</sup> to 1.5 t ha<sup>-1</sup> were comparable, and 5 hybrids had 13.5 to 17.5 Brix values, significantly superior to ICSSH 8 (10) and NSSH 104 (7.3).

**International sweet sorghum hybrids trial (ISSHT, 2006R):** A total of 44 hybrids selected from sweet sorghum hybrid trials in previous evaluations were evaluated along with the check SSV 84 during the 2006 rainy and postrainy seasons. Data were collected on agronomic traits and juice-related traits at flowering and maturity. The data revealed interesting results. Ranking of hybrids based on sugar yield (t ha<sup>-1</sup>) varied at flowering and at maturity. The hybrids ICSA 24001 × ICSV 93046 (2.12 t ha<sup>-1</sup>), ICSA 324 × NTJ 2 (1.91 t ha<sup>-1</sup>) and ICSA 324 × SSV 74 (1.83 t ha<sup>-1</sup>) that ranked 1, 2 and 3 for sugar yield at maturity, ranked 37 (1.43 t ha<sup>-1</sup>), 44 (1.67 t ha<sup>-1</sup>) and 33 (1.32 t ha<sup>-1</sup>) at flowering, respectively. Compared to the check SSV 84 (1.06 t ha<sup>-1</sup>), 11 hybrids with a range of 1.67 to 2.12 t ha<sup>-1</sup> performed significantly better for sugar yield at maturity and were comparable for grain yield (range of 5.07 to 8.97 t ha<sup>-1</sup> compared to SSV 84: 6.76 t ha<sup>-1</sup>). Brix in these 11 hybrids ranged from 10 to 13 (SSV 84: 10). It is good to have some genotypes producing more sugar at flowering stage and some during maturity stage, as it increases the feed stock availability and enables continuous supply of feed stocks to the distillery. However, it is advisable to cut at maturity, as grain can be used for food or feed.

**Sweet sorghum advanced hybrids trial (SSAHT, 2006R):** A total of 27 hybrids selected from the sweet sorghum preliminary hybrid trial, were evaluated in SSAHT along with the checks SSV 74, SSV 84 and NSSH 104. Compared to the check NSSH 104 (1.5 t ha<sup>-1</sup>), 5 hybrids with a range of 2.1 to 2.3 t ha<sup>-1</sup> were significantly

superior for sugar yield and were on par with SSV 74 (2.0 t ha<sup>-1</sup>). However 18 hybrids (with sugar yield range of 1.1 to 2.3 t ha<sup>-1</sup>) were significantly superior over SSV 84 (0.5 t ha<sup>-1</sup>).

**Sweet sorghum preliminary hybrid trial (SSPHT, 2006R):** Nineteen female lines were crossed with nine restorer lines in L×T design to generate 171 hybrids. Hybrids were evaluated along with parents and a check (NSSH 104) during the 2006 postrainy season. Based on sugar yield at flowering, 124 hybrids were selected and evaluated along with the parents and check at maturity. Compared to the check NSSH 104 (0.8 t ha<sup>-1</sup>), 54 hybrids with a range of 1.4 to 2.9 t ha<sup>-1</sup> were significantly superior for sugar yield. Compared to SSV 84 (one of the parents and a check) (0.9 t ha<sup>-1</sup>), 47 hybrids (1.5 to 2.9 t ha<sup>-1</sup>) were significantly superior for sugar yield.

**Sweet sorghum fertilizer effect assessment trial (SSFT 2006R):** Five sorghum genotypes (a hybrid - ICSA 475 × E 36-1 and 4 varieties - SPV 422, PVK 801, ICSR 89068 and NTJ 2) were evaluated during the 2006 postrainy season for their response to varying Nitrogen (N) fertility levels. The experiment was laid out in a strip plot design with four replications. Each plot consisted of a genotype grown in 4 rows of 4m length each, and a spacing of 75 cm between rows and 12 cm between plants in a row was maintained. The treatments included four N-levels (T1- No fertilizer applied, T2-basal, T3-basal+1 top dressing and T4-basal+2 top dressings; basal – 18 kg N ha<sup>-1</sup>+28 kg P ha<sup>-1</sup>, top dressing – 46 kg N ha<sup>-1</sup>). Data were recorded for agronomic traits (days to 50% flowering, plant height, plant agronomic performance, biomass, lodging, stay-green and grain yield) and sugar stalk traits at flowering and maturity (fresh stalk yield, cane yield, juice yield, juice volume, stillage, Brix and sugar yield). Significant differences were observed among the genotypes for sugar yield and grain yield at maturity indicating the differences between genotypes. Fertilizer effects were also significant denoting that the genotypes responded significantly to different fertility levels. However, different genotypes responded differentially for sugar yield to varying fertility levels as seen by the significant fertilizer × genotype interaction effects. T1 was on par with T2, and T3 was on par with T4 for sugar yield indicating that Basal + one top dressing is sufficient to obtain maximum sugar yield at maturity. However for grain yield, T1, T2 and T3 were on par with each other. T4 was significantly superior to T1, T2 and T3, indicating that Basal + two top dressings can be employed for realizing good grain yields. In order to realize maximum sugar and grain yields, it is essential to go for a basal dose of fertilizer followed by two top dressings.

**Sweet sorghum date of sowing trial (SSDOST 2007):** Sweet sorghum can be efficiently used as a feed stock for distilleries if it can be cultivated over an extended period of time. However, such studies are limited. In order to assess the feasibility of cultivating sweet sorghum all round the year, a trial including three hybrids and two varieties was planted monthly (once in each month starting from March 28 onwards). Observations were recorded for all the sugar yield related parameters at three different stages – flowering, dough and maturity. There was significant influence of sowing dates (I: 28 March, II: 27 April and III: 28 May sowing dates) on sugar yield. II and III dates were on par with each other but were significantly superior to the first date for sugar yield. The genotypic variance was significant suggesting significant genetic variability. Hybrids were on par with each other and significantly superior over varieties in all three dates of sowing. However, sowing date did not interact significantly with the genotypes denoting that the best genotype for sugar yield in one environment remained so in other environments also. Hence it is possible to select a genotype that performs consistently better than the others for sowing over an extended period of time. Stage of harvest significantly influenced sugar yields in all the genotypes. In general, sugar yield increased from flowering to maturity. However, appropriate stage of harvest for obtaining higher sugar yield is influenced by the genotype, sowing date and the interaction of genotype with sowing date.

**Sweet sorghum advanced B-lines trial (SSABLT, 2006R):** Based on the performance of B-lines in the previous sweet sorghum B-lines trials (in the 2004 postrainy season, 2005 rainy and postrainy seasons), PPV (Protection of Plant Varieties) trials in the 2004 rainy and postrainy seasons, 2005 rainy and postrainy seasons, 75 B-lines were selected and evaluated during the 2006 rainy season along with the checks 296B and SSV 84 and repeated in the 2006 postrainy season. Two B-lines, ICSB 474 (1.2 t ha<sup>-1</sup>), ICSB 360 (1.1 t ha<sup>-1</sup>) were superior to the check SSV 84 (0.8 t ha<sup>-1</sup>) for sugar yield. Among these, ICSB 474 (6.0 t ha<sup>-1</sup>) was significantly superior to the check 296 B (3.7 t ha<sup>-1</sup>) for grain yield. Apart from these, 11 B-lines with a sugar yield range of 0.6 to 1.0 t ha<sup>-1</sup> were on par with SSV 84. In the 13 B-lines, Brix value ranged from 7.3 to 15.0 (SSV 84: 8.0) and the grain yield ranged from 2.9 to 11.4 t ha<sup>-1</sup>.

From the 182 F<sub>3</sub>s and 55 F<sub>5</sub>s evaluated for sweet sorghum B-line development, 134 F<sub>4</sub>s and 62 F<sub>6</sub>s were selected. In a different set, 87 F<sub>3</sub>s and 59 F<sub>5</sub>s were evaluated for sweet sorghum B-line development, and 27 F<sub>4</sub>s and 72 F<sub>6</sub>s were produced. From the 286 F<sub>1</sub>s (R×R) and 178 F<sub>1</sub>s (R×R and B×B/R), 349 F<sub>1</sub>s were selected and F<sub>2</sub>s were produced during the 2007 rainy season. All these progenies will be advanced with selection during the

2007 postrainy season. From the forage sorghum material developed at ICRISAT based on the seed availability, 275 lines are being evaluated in a nursery during the 2007 late rainy season for sweet stalk traits.

BVS Reddy and A Ashok Kumar

*Milestone: 5A.7.1.2: Six new high-yielding sweet sorghum restorers identified (BVSR/HDU, 2008)*

**Sweet sorghum advanced varietal and restorer lines trial (SSAVRT, 2006R):** Thirty-six varieties/ restorers selected for sweet stalk trait were evaluated in sweet stalk advanced varieties/ restorers trial along with the checks SSV 74, SSV 84 and NSSH 104. Compared to the best check SSV 74 (1.7 t ha<sup>-1</sup>), four varieties SP 4511-2 (2.7 t ha<sup>-1</sup>), SS 2016 (2.6 t ha<sup>-1</sup>) and SP 4511-3 (2.3 t ha<sup>-1</sup>) and ICSV 93046 (2.2 t ha<sup>-1</sup>) performed significantly better for sugar yield. However, compared to SSV 84 (0.5 t ha<sup>-1</sup>), 21 varieties with a range of 1.0 to 2.7 t ha<sup>-1</sup> were significantly superior for sugar yield. The top four varieties (5.4 to 8.6 t ha<sup>-1</sup>) were on par with SSV 74 (6.9 t ha<sup>-1</sup>) and SSV 84 (7.5 t ha<sup>-1</sup>) for grain yield.

BVS Reddy, A Ashok Kumar and HD Upadhyaya

**Output target 5A.8: Stay-green QTLs associated with improved fodder quality introgressed into elite sorghum hybrid parents and their potential utility assessed (2010)**

**Activity 5A. 8.1: Mapping and introgression of stay-green QTL into elite parental lines, and assessment of their effects on hybrid performance**

*Milestone 5A.8.1.1: Assessment of near-isogenic BC<sub>3</sub>F<sub>3</sub> and BC<sub>4</sub>F<sub>3</sub> stay-green QTL introgression lines completed in R 16 and ISIAP Dorado backgrounds (CTH/SPD/VV/FRB, 2010)*

We conducted first field evaluations of advanced (BC<sub>3</sub> and BC<sub>4</sub>) stay-green versions of the Indian rabi line R 16 during the 2006-2007 postrainy season. These lines were bred by marker-assisted introgression of favorable alleles at several stay-green QTL from B 35 (the stay-green donor parent) with background selection for the R 16 alleles. Replicated evaluations were done in shallow vertic inceptosol (severe stress) and deep vertisol (mild stress) fields. In the deeper soil, the onset of stress did not occur until after flowering, but in the shallow soil stress was evident before flowering, resulting in considerably lower mean grain number per panicle in the shallow soil (909) than in the deeper soil (1331). Mean individual grain mass was identical in the two environments, however, so the mean yield difference between the two environments was a function of the pre-flowering reduction in grain numbers rather than post-flowering differences in grain filling. Yield differences between R 16 and its derivatives within each environment were also primarily a function of differences in grain numbers ( $r \geq 0.62$ ,  $P < 0.02$ , in both cases) rather than differences in grain size ( $r \leq 0.17$ ,  $P > 0.55$ ) in both cases), which suggests that yield differences in the introgression lines were due to pre-flowering differences rather than post-flowering differences.

Differential stay-green expression was excellent in the moderate stress environment, where 8 of the 14 putative stay-green lines had a significantly ( $P < 0.05$ ) greater percent green leaf area during the middle and late grain-filling stages than the recurrent parent R 16. Percent green leaf area during the latter half of grain-filling was also positively ( $P < 0.05$ ) correlated to individual grain mass, as expected. However, this did not translate to a correlation of green leaf area and grain yield, due to the lack of relationship between individual grain mass itself and grain yield. Differences in stay-green are likely to affect grain yield primarily where differences in grain filling are the major reason for differences in grain yield. This should have been the case with true isogenic lines, as grain number should not have differed significantly among isogenic lines in the absence of pre-flowering stress. This was not the case, however, as grain number per panicle ranged from 1046 to 1589 among the stay-green lines. Additional backcrosses may be required to completely recover the R 16 background phenotype. The data also suggested that stay-green expression may have been influenced by grain numbers per panicle (ie, by sink demand), as green leaf area in the mid to late grain filling period was negatively related ( $r = 0.5$  to  $0.7$ ,  $P < 0.05$ ) to grain number per panicle.

Under the more severe stress conditions, leaf senescence was more rapid (and more similar) in all entries through much of grain filling, apart from the final week where a number of the stay-green derivatives retained a significantly ( $P < 0.05$ ) greater green leaf area than R16. However, there were no correlations between percentage green leaf area and either individual grain mass, grain number per panicle or grain yield in this experiment. It is likely that the stress was too early and too severe for a clear expression of stay-green differences among the introgression lines.

Early generation product from the backcrossing program (BC1F3 and BC2F3 materials), using B 35 as a stay-green donor parent and R 16 and ISIAP Dorado as senescent parents were tested under both water-stressed (WS) and well-watered (WW) conditions in a vertisol field. Grain and stover yields under WS were respectively 78% and 75% of the grain and stover yields under WW conditions, indicative of a moderate stress, which was in part due to an unplanned extra irrigation of about 40 mm at 40 days after sowing. Under such conditions, one derivative from R 16 (RSG 04001) had significantly higher grain yield under WS than recurrent parent R 16. Similarly, one derivative from ISIAP Dorado, IDSG 04211 had higher grain yield under WS than recurrent parent ISIAP Dorado. Under these conditions, E 36-1 and RSG04012 (a re-selection from a cross between R 16 and E 36-1) also had higher grain and stover yield than R 16.

Vincent Vadez, FR Bidinger and CT Hash

*Milestone 5A.8.1.2: Stay-green QTL mapping of E 36-1 confirmed based on phenotypic assessment of two F<sub>6</sub> RIL populations genotyped with DArT, SSR, and CISP-SNP markers (CTH/SS/SPD/VV, 2010)*

Seed of two ICRISAT sorghum RIL populations [ICSP 73001, comprised of 221 F7 random inbred lines derived from (N13 × E 36-1); and ICSP 74000, comprised of 223 F7 random inbred lines derived from (IS 9830 × E 36-1)] was multiplied during the 2006/07 postrainy season and seed samples provided to the ICRISAT Genebank for long term conservation. Maxi-prep DNA samples were produced for each of the 444 RILs and their parental lines for future use in genotyping these mapping populations. Funds to pay for genotyping ICSP 73001 were awarded as part of a new BBSRC-DFID SARID grant, and will be available in 2008.

C Tom Hash, Santosh P Deshpande,  
S Senthilvel and Vincent Vadez

*Milestone 5A.8.1.3: Stay-green QTL introgression sorghum lines based on donor parent E 36-1 available for phenotypic evaluation in two diverse genetic backgrounds (CTH/SPD, 2011)*

See report for milestone 5A.8.1.2 above.

*Milestone 5A.8.1.4: Initial evaluation of animal performance on near-isogenic hybrids differing in allelic composition at two stay-green QTL completed (CTH/SPD/MB/BVSR, 2010)*

A trial of stay-green QTL introgression lines based on donor parent B35 and recurrent parent S 35 (a dual-purposed sorghum variety with juicy sweet stems producing highly palatable fodder) was sown in five managed environments at ICRISAT-Patancheru during the 2007/08 postrainy season following seed multiplication of finished single- and multiple-QTL introgression lines during the 2006/07 postrainy season. Stover samples of all entries from the fully-irrigated control environment(s) will be analyzed by near-infrared reflectance spectroscopy (NIRS) to predict their ruminant livestock feeding values. The best entries (along with recurrent parent S 35) will then be test crossed to several male-sterile lines, permitting assessment of expression of these stay-green QTLs in hybrid combinations. The best of these hybrids (along with the recurrent parent's control hybrid) will then be multiplied and their stover used on livestock feeding trials.

C Tom Hash, Santosh P Deshpande, S Senthilvel,  
Fran Bidinger and Michael Blümmel

## **Output target 5A.9: Commercialization of sorghum grains and impact of improved germplasm enhanced**

### **Activity 5A.9.1: Strengthen research and development partnerships and technology exchange**

Seven scientists representing coalition partners under CFC project from China and Thailand visited ICRISAT and underwent an international training on "Detection and management of mycotoxins in sorghum and pearl millet". These included two from Sorghum Research Institute (SRI) of Liaoning Academy of Agricultural Sciences (LAAS), Liaoning, Peoples Republic of China; and five from Field Crops Research Institute (FCRI), Bangkok and Field Crops Research Centers (FCRC) in Suphan Buri, Kanchan Buri and Nakhon Sawan provinces in Thailand. They also visited sorghum growing areas in India under the CFC project to understand the opportunities and constraints in sorghum cultivation and utilization in India. Three Indian scientists (two from partner organizations and one from ICRISAT) visited China for a learning visit.

*Milestone 5A.9.1.1: Hybrid parents (>50) and other breeding materials (>100) supplied to NARS and their impact assessed (BVSR/sorghum team—annual)*

Public and private sector scientists utilize ICRISAT-bred hybrid parents for developing commercial hybrids. To assess the performance of sorghum hybrids produced by different private and public sector organizations, “Seed producers’ sorghum hybrid trials” are coordinated in rainy and post-rainy seasons by ICRISAT as one of the activities of ICRISAT-Private sector Sorghum Hybrids Parents Research Consortium. Under this activity, during the 2007 rainy season SPSHT 2007-K trial with 20 entries (17 hybrids contributed by 10 seed companies, one ICRISAT advanced hybrid, one NRCS-released hybrid as control, and one local control) was conducted at locations of seven consortium members (Basant AgroTech and Maharashtra State Seeds Corporation Ltd, Akola; Biostadt MHseeds, Aurangabad; Krishidhan Seeds, Jalna; Bioseeds, JK Agri Genetics, and Nuziveedu Seeds, Hyderabad) and also at ICRISAT-Patancheru. The data are yet to be received from the test locations.

ICRISAT’s sorghum hybrid parents’ research has strengthened the genetic base of the research programs of consortium member seed companies (18) and NARS partners. For instance, five seed companies revealed that they were using 370 A/B pairs and 241 R-lines selected from ICRISAT-bred materials in their research programs during 2000–2006. Ten seed companies provided information that they have developed 15 sorghum hybrids using ICRISAT sorghum hybrid parents and are in marketing. Of these, six hybrids have both hybrid parents with 50–75% ICRISAT-bred improved germplasm; four hybrids have both the hybrid parents with 25–50%; two hybrids have both the A- and R- lines with 100% ICRISAT-bred improved germplasm; two hybrids have only R-lines with 100% ICRISAT-bred germplasm, and one hybrid involves both A- and R-lines bred by ICRISAT. The consortium funding of ICRISAT’s sorghum hybrid parents research has also considerably enhanced the Institute’s ability and benefited both seed companies and seed producing farmers. One of the seed companies indicated that they are marketing an average of 370 t sorghum annually, earning a net profit of US\$ 52706 per year from sorghum seed production. Farmers are also earning an average of US\$ 911 ha<sup>-1</sup> net income through sorghum hybrid seed production.

A total of 3384 seed samples of hybrid parents/breeding lines were sent to 14 countries. India received 2675 samples followed by Uzbekistan (288 samples). Of the 2675 seed samples to India, 1259 were sent to public sector scientists, 1342 to private sector scientists and the remaining 74 samples to farmers and NGOs/collaborators. Seed in bulk quantities (170 kg) of seven high-yielding/released cultivars were supplied to 50 farmers.

Fifteen kg seed of each of the eight released/high yielding varieties (S 35, CSV 15, PVK 801, ICSV 574, ICSV 745, ICSV 93046, SPV 1411 and SPV 1616) were supplied to Orissa Tribal Empowerment and Livelihoods Program (OTELP), Bhubhaneswar, Orissa for rainy season adaptation in Orissa tribal areas. Seed of seven varieties weighing 173 kg [ICSR 93034 (3.5 kg), ICSV 745 (4.5), ICSV 112 (5), ICSV 93046 (30), JJ1041 (30), S 35 (50), CSV 15 (50)] and four sets of varieties (29 entries) trial were supplied to International Center for Bio-Saline Agriculture (ICBA), Dubai for salinity screening. Dual-purpose varieties (19 entries) trial and salinity trial (29 entries) each 6 sets were sent to Tashkent, Uzbekistan.

Seed of sweet sorghum varieties (4), B-lines (3) and hybrids (3) was multiplied and sent to National Research Centre for Sorghum (NRCS), Hyderabad, India, for testing at the All India Coordinated Sorghum Improvement Project (AICSIP) locations in the 2007 rainy season. Salinity tolerant lines (21), Acid soil tolerant lines (12), *Striga* tolerant lines (20) for screenings and Sudan sorghum landraces (93) for downy mildew screening were sent to NRCS, Hyderabad, India.

BVS Reddy and A Ashok Kumar

*Milestone 5A.9.1.2: Ten sorghum scientists trained biannually (BVSR/sorghum team—alternate year)*

International learning program on “Sorghum hybrid parents and hybrid research and development” was conducted from 6 to 17 February 2007, jointly by ICRISAT-Patancheru and National Research Center for Sorghum, Hyderabad, India. There were 18 participants from both public and private sectors in India, Philippines (one) and Sudan (one).

BVS Reddy and A Ashok Kumar

*Milestone 5A.9.1.3: Two thousand farmers adopt improved sorghum cultivars and crop production practices in India, China and Thailand (ASA/ChRR/BVSR/PPR/CLL/FW, 2007)*

More than 4000 farmers from India adopted 20 improved cultivars, 600 farmers in China adopted 15 cultivars, and 600 farmers in Thailand adopted 10 cultivars. The farmers were trained through season-long training (20 trainings in India, 2 in China and 3 in Thailand) on use of improved cultivars of sorghum, adoption of improved

production technologies suitable to each location by adopting integrated nutrient management practices in sorghum production. The sorghum production technologies in English, Marathi, Telugu, Kannada, Chinese and Thai languages were published for the benefit of the farmers. The project also identified new areas outside primary target areas wherein new farmers joined the project. The efforts of identifying new seed sources and cultivars continued. Field level demonstrations on improved production technologies to enhance production were conducted on the farmers' fields. Women's participation was increased through the involvement of women farmers' self help groups (SHGs) in project activities. For the dissemination of the project experiences to wider groups, field days, radio talks, learning visits, publications, press releases, website, etc., were used as tools.

AS Alur, BVS Reddy, Ch Ravinder Reddy,  
P Parthasarathy Rao, CLL Gowda and F Waliyar

*Milestone 5A.9.1.4: Market linkages for the sale of sorghum grain (100 t) to poultry feed manufacturers by sorghum farmers in India, China and Thailand established (ASA/ChRR/BVSR/PPR/CLLG/FW, 2008)*

The project aimed at strengthening the input and output linkages for the benefit of the project farmers. The farmers associations were given training and exposure so as to enable them to take timely decisions on market-related issues. The project also explored the possibility of alternative market opportunities for target crops and four meetings with potential buyers and three joint dialogues with alternate end users were organized to arrive at marketing agreements between the farmers and the industry groups. The management committee members were trained in marketing linkages and price negotiation skills with an objective to ensure that they develop capacities to handle the future market negotiations on their own. A contract farming model was developed and tested in China during the current year. The farmers from one cluster in China have already sold 1050 tons of sorghum during this year to three companies. The sale of grains is in progress in India and so far sale of 300 tons of sorghum has been completed.

AS Alur, BVS Reddy, Ch Ravinder Reddy,  
P Parthasarathy Rao, CLL Gowda and F Waliyar

## II. Pearl millet

**Output target 5A.1: Genetically diverse, high-yielding and downy mildew (DM) resistant pearl millet parental lines of potential grain hybrids (at least 9 each of seed parents and restorer parents) developed annually during 2006-2011**

**Activity 5A.1.1: Develop and characterize regionally adapted high-yielding and DM resistant hybrid parents**

*Milestone 5A.1.1.1: Diverse range of high-yielding and DM resistant seed parents and restorer parents developed (KNR/RB/RPT/RS, annual)*

One of the major objectives, ie, to develop and disseminate morphologically diverse A-lines with high grain yield potential and downy mildew resistance every year has been contributing to strengthen the hybrid development programs in the public and the private sector. In 2007, nine 2007-series A-lines (2 A<sub>1</sub>, 3 A<sub>4</sub>, 3 A<sub>1/4</sub> and 1 A<sub>5</sub> cytoplasm) with 49-61 days to flowering, 12-30 cm panicle length and 8.1-12.8 g 1000-seed mass were developed for dissemination. Under high disease pressure in the glasshouse (more than 95% DM incidence in susceptible check 843B), eight of these were highly resistant (0-10% DM incidence) to all the five diverse pathotypes (Jodhpur, Jalna, Jamnagar, Durgapura and Delhi), and one was resistant to three pathotypes (Jodhpur, Durgapura and Delhi).

About 180 B-lines and their counterpart backcross (BC) progenies were evaluated and backcrossed for further advancement for A-line breeding. Of these, 131 B-lines and their BC<sub>4</sub>-BC<sub>10</sub> progenies (57 A<sub>1</sub>, 74 A<sub>4</sub> and 57 A<sub>5</sub>) were selected for further advancement. Another set of 105 B-lines and their early generation BC progenies (30 A<sub>1</sub>, 63 A<sub>4</sub> and 63 A<sub>5</sub>) were evaluated, of which 81 B-lines were selected for advancing to BC<sub>2</sub>-BC<sub>4</sub>. Similarly, 728 testcrosses (274 A<sub>1</sub>, 240 A<sub>4</sub> and 214 A<sub>5</sub>) involving 296 B-lines were made in the 2007 summer season and were field evaluated during the rainy season. About 28% of the testcross progenies showed fertility restoration, 14% showed sterility/fertility reaction and the remaining 58% showed sterility reaction.

In a continuing effort of pyramiding DM resistance genes into ICMB 89111, all the 22 BC<sub>5</sub>F<sub>5</sub> progenies were evaluated during the rainy season, of which nine were selected based on visual assessment of agronomic

performance and plant type of ICMA 89111. All the selected progenies flowered in 45–50 days (ICMB 89111 flowered in 45 days).

A similar approach of development and dissemination, as followed for A-lines, has been initiated in the restorer line program. Based on high agronomic performance over seven seasons (rainy 2004, rainy 2005, postrainy 2005, rainy 2006, postrainy 2006, rainy 2007 and postrainy 2007), 27 elite restorer progenies were selected for DM screening against five pathotypes (Jalna, Durgapura, Jamnagar, Jodhpur and Patancheru) along with 3 checks. Of these, eight progenies were resistant to all the five pathotypes with 0–10% disease incidence (susceptible checks 7042S and ICMP 451 had more than 90% disease incidence) and two of these had less than 10% disease incidence against four of the five diverse pathotypes and, seven were resistant to three pathotypes with less than 10% disease incidence. Therefore, based on high agronomic performance and resistance to at least two DM pathotypes, nine 2007-series restorer progenies with 42–55 days to flowering and 15–28 cm panicle length were selected for designation and dissemination in 2007.

KN Rai, Ranjana Bhattacharjee and RP Thakur

*Milestone 5A.1.1.2: Seed parents and restorer parents adapted to arid zone developed (KNR/RB/FRB/RPT/RS, 2010)*

**Seed parent progenies:** Two types of materials were generated that have been further evaluated and advanced: (i) progenies derived from ICRISAT-CAZRI B-composite (ICZBC), and (ii) progenies derived by pedigree breeding in some of the most promising B × B crosses in the above diallel. About 533 S<sub>4</sub> progenies derived from ICZBC were evaluated during the 2007 summer drought nursery, of which 182 were selected, with 23 of these flowering in 41–45 days and 100 flowering in 46–50 days (checks 843B flowered in 42 days and 81B in 56 days). Another 38 S<sub>2</sub>/S<sub>3</sub>/S<sub>4</sub> progenies were evaluated, of which 21 were selected based on the visual assessment of agronomic performance. Of these, 4 progenies flowered in 41–45 days and 11 flowered in 46–50 days (checks 843B flowered in 44 days and 842B in 47 days). In addition, 85 S<sub>5</sub> progenies were also evaluated in a summer drought nursery of which 16 selected progenies flowered between 46–55 days. We also evaluated 116 hybrids from the cross (ICZBC × MRC) during the summer season, of which 53 were selected based on visual assessment for yield potential and agronomic traits. All the selected progenies flowered in 40–50 days. Additional 107 F<sub>7</sub>/F<sub>8</sub> progenies (including progenies from CAZRI) that were derived from B × B crosses during the 2006 rainy season, were evaluated, of which 42 were selected with 19 of these flowering in 41–50 days and 23 flowering in 51–60 days (checks ICMB 95444 flowered in 48 days, ICMB 92111 in 54 days and ICMB 93333 in 47 days).

Under heavy disease pressure (with more than 88% disease incidence in susceptible check entries ICMP 451 and 7042S), 85 S<sub>5</sub> progenies of ICZBC were screened against Jodhpur pathotype. Of these, 49 progenies showed less than 10% disease incidence and 12 progenies showed 11–20% disease incidence. Similarly, 38 early-generation progenies (S<sub>2</sub>/S<sub>3</sub>/S<sub>4</sub>) of ICZBC were screened against Jodhpur pathotype with 8 progenies showing less than 10% disease incidence and 8 progenies with 11–20% disease incidence. We also screened 415 S<sub>4</sub> progenies of ICZBC against Jodhpur pathotype, of which 211 showed less than 10% disease incidence and 35 progenies showed 11–20% disease incidence. Another set of 38 drought tolerant ICZBC and MRC progenies were screened against Jodhpur pathotype, of which 16 showed less than 10% disease incidence and 6 progenies showed 11–20% disease incidence.

In addition, 107 B × B advance generation progenies (F<sub>7</sub>/F<sub>8</sub>) were screened under heavy disease pressure against Jodhpur pathotype with 28 progenies showing less than 10% disease incidence (susceptible checks 7042S and ICMP 451 had more than 88% disease incidence) and 16 progenies showed 11–20% disease incidence.

**Performance of hybrids with probable adaptation to arid Rajasthan (India):** The traits that are considered most important in breeding for hybrids adapted to the arid zone of Rajasthan is different from that of Maharashtra (India). Early maturity and high tillering are the most important traits and breeding of hybrid parental lines for arid Rajasthan is concentrated around basic phenotypes of male-sterile lines such as 843A and pollinator lines such as H 77/833-2. For this purpose, about 16 MRC-derived advanced generation progenies were crossed on six A-lines (843A, ICMA 03666, ICMA 96111, ICMA 00222, ICMA 04666 and ICMA 00999) during the 2005 summer season, and the resultant hybrids were evaluated for the second time in a drought nursery at Patancheru during the 2007 summer season, with HHB 67, HHB 67-2 and ICMH 356 as checks. Out of 25 hybrids evaluated, 15 were selected based on visual assessment for agronomic performance, of which 73%

flowered in 40–50 days and 4 flowered within 40 days (checks HHB 67 flowered in 37 days, HHB 67-2 in 39 days and ICMH 356 in 41 days). Twelve out of 16 restorers gave fertile reaction on at least two A-lines. All the selected hybrids produced higher grain yield (2581–4023 kg ha<sup>-1</sup>) and fodder yield (2.6–3.5 t ha<sup>-1</sup>) in comparison to the check HHB 67 (2576 kg ha<sup>-1</sup> grain yield and 2.0 t ha<sup>-1</sup> fodder yield). In another study, about 5 MRC-derived advanced generation restorers and one AIMP 92901 derived advanced generation restorer were crossed on six A-lines (ICMA 00333, ICMA 00666, ICMA 04333, ICMA 05666, ICMA 95444 and ICMA 99222). All the 13 resultant hybrids were selected based on agronomic evaluation, of which seven flowered in 40–50 days and 6 flowered within 40 days. Three out of 6 restorers gave fertile reaction on at least two A-lines.

**Restorer parent progenies:** About 40 MRC-derived progenies ( $S_8/S_9$ ) were evaluated in the drought nursery during the summer season, of which 34 were selected based on visual assessment for agronomic traits. Of these, 26 flowered in 40–50 days (check ICMR 356 flowered in 52 days).

KN Rai, Ranjana Bhattacharjee and RP Thakur

**Heterosis in arid zone landrace-derived restorer populations:** Over the past several years, heterosis for both grain and stover yields has been evaluated in a set of restorer populations, which have been bred from various arid zone landraces and landrace population sources. These restorer populations are intended as a source of improved germplasm for the breeding of pollinators, which are well adapted to the arid zone. Heterosis (percent increase over the restorer population mean) was measured in six such populations (based on individual landrace accessions, landrace-based composites and open-pollinated varieties), and 10 to 13 A-lines per restorer population. Heterosis for grain yield averaged 18% (range 3 to 39%) on a restorer population basis. Heterosis for stover yield, however, averaged at -2% (range -22% to +17%) on a restorer population basis. The reason for this was that heterosis occurred mainly as an increase in harvest index (HI), averaging at 17% (range of 1% to 32%) on a restorer population basis, rather than an increase in biomass.

Regression modeling of the expression of grain and stover yield heterosis (based on individual A-line × restorer population data) suggested that 20% heterosis in HI would result in a 19% gain in hybrid grain yield but 9% decrease in hybrid stover yield, compared to the yields of the restorer population itself. In contrast, 20% heterosis in biomass would result in a 21% gain in both grain and stover yield in the hybrids, compared to that of the restorer population. Finally, 10% heterosis in both biomass and HI, would result in a 20% gain in grain yield in the hybrid, accompanied by a 6% gain in stover yield. Clearly for farmers who value both grain (for their families) and stover (for their animals), it is necessary that restorers for the arid zone are capable of heterosis for biomass as well as for HI.

The best individual testcross (selected on the basis of biomass heterosis) of each of the six restorer populations indicated that this could be achieved in selected testcross hybrids. The average heterosis for biomass, in the best individual testcrosses of each restorer population, was 21% (range 9% to 34%). This was accompanied, in the same testcrosses by an average heterosis for HI of 17% (range -9% to +49%). The result was an average grain yield heterosis of 33% (range of 17% to 47%) and an average stover yield heterosis of 18% (range of 1% to 38%). So clearly the combination of significant heterosis for both biomass and HI is achievable in specific combinations of A-line and restorer population. Given that the above data is based on restorer populations in which a very limited breeding effort has been invested, it should be readily possible to identify partial inbred lines from them, with at least the same degree of heterosis as measured in the parent population testcrosses. It will be necessary, however, to measure both biomass and grain in testcross trials of such lines to identify those combinations with significant heterosis for both biomass and HI.

FR Bidinger

**Identification of new arid zone restorers:** We also completed the evaluation of a set of partially inbred restorers selected from the Mandor Restorer Composite (MRC), which was bred by recombining a set of selected inbred restorers with the earliness and plant type required for the arid zone, from ICRISAT and various AICPMIP breeding programs. Forty-three MRC lines plus five checks were crossed to five A-lines, and the resulting 240 entries evaluated in replicated trials in the arid zone in 2005, 2006 and 2007. The analysis compared the restorers for general combining ability (GCA) for time to flowering, biomass and harvest index and for grain and stover yield across environments.

Results were very encouraging as evident from both the comparison of the range in MRC progeny values to the mean values for ICMR 01004 (improved version of H 77833-2, the restorer of HHB 67) and ICMR 356 (the restorer of ICMH 356) and in terms of the numbers of lines with a significant positive combining ability for



various traits. In the cases of time to flowering, harvest index and grain yield, the hybrids made with the two inbred checks were slightly better than the mean of all hybrids made with the MRC lines, but the hybrids on the best of the MRC lines were as good as or better than the hybrids made with the inbred checks. In the case of biomass and stover yields the mean of the hybrids made with the MRC lines was as good as or better than hybrids made with the inbred checks; the hybrids made with the best individual MRC lines were clearly superior. The two inbred checks had a significant positive GCA for earliness and HI but not for any of the productivity traits. In comparison, between 20 and 25% of the MRC lines had a positive GCA in the case of each trait. Therefore there should be every opportunity to identify MRC restorers that can produce hybrids with performance in the arid zone that is superior to the existing hybrids.

The landrace restorer population based on the Early Rajasthan Population also indicated considerable promise, as it had a significant CGA for all traits and its hybrids had a *per se* performance, which was equal or superior to that of the hybrids of the inbred checks. Additional breeding effort will be required in this population, mainly to improve disease resistance, but it should be possible to produce useful restorer lines from it as well.

FR Bidinger and KN Rai

**Output target 5A.2: More than 500 trait-specific and DM resistant improved breeding lines of pearl millet developed and disseminated alternate years (2006, 2008, 2010 and 2012) for use in breeding parental lines of grain hybrids**

**Activity 5A.2.1: Develop a diverse range of high-yielding and DM resistant trait-specific breeding lines**

*Milestone 5A.2.1.1: Germplasm with large seed, high biomass yield, white grain color and large panicles identified and introgressed (KNR/RB/HDU/RPT/RS, 2009)*

**Grain size:** Large grain size is an important grain yield component and a farmer-preferred trait. There are germplasm lines with 19–20 g of 1000-grain mass that provide an opportunity to develop OPVs and hybrids with 1000-grain mass in excess of 16 g. Recent attempts to introgress this large grain size in the adapted and elite genetic backgrounds have made considerable progress. Based on the visual assessment of 195 F<sub>6</sub> and advanced progenies for grain size and other agronomic traits, 101 were selected of which 66 flowered in 41–50 days and 34 in 51–65 days (45 days for the check ICMB 00444). There was one progeny that flowered in less than 40 days. There were 37 progenies that had more than 15 g of 1000-grain mass, with 3 of these having 18–20 g of 1000-grain mass and two with >20 g of 1000-grain mass. In another large-seeded seed parent nursery, 222 three-way F<sub>4</sub> progenies had been evaluated. Based on grain size and other agronomic traits, 62 progenies were selected, of which 35 flowered in 46–55 days and remaining 27 flowered in 56–65 days. There were 33 progenies that had more than 15 g of 1000-grain mass, with 6 of these having 18–20 g of 1000-grain mass and 3 with >20 g of 1000-grain mass. In addition, 50 large-seeded three-way F<sub>2</sub> progenies were also evaluated, of which 17 were selected. Five of the selected progenies flowered in 41–50 days and remaining 12 in 51–60 days. There were 13 progenies with more than 15 g of 1000-grain mass, with 8 of these having 18–20 g of 1000-grain mass and 2 with >20 g of 1000-grain mass.

**Panicle length:** There are germplasm lines with panicle length of 140 cm, and opportunities exist to develop improved breeding lines with 60–80 cm long panicles, much longer than 20–25 cm long panicles in commercial hybrids. These germplasm accessions, however, are late maturing (70–80 days to flowering) and tall (>250 cm), with sparse spikelet density in the basal portion of the panicles. Considerable success has already been made in introgressing this trait from the germplasm into elite and adaptive backgrounds. For instance, in restorer parents research, about 1414 early generation long spike progenies (F<sub>2</sub>/F<sub>3</sub>/F<sub>4</sub>) were evaluated during the 2007 rainy season, of which 372 were selected based on visual assessment of spike length and agronomic score for further evaluation. About 74 of these flowered in 40–50 days, while 176 progenies flowered in 51–55 days (check NCd<sub>2</sub> flowered in 51 days and had panicle length of 41 cm). Similarly, 911 advanced generation progenies were planted during the rainy season, of which 215 were selected based on visual assessment for agronomic performance and panicle length with 97 progenies flowering in 46–55 days and 106 progenies flowering in 56–60 days.

**Grain color:** The consumer preference for white grain color in pearl millet stills remains to be ascertained, though the flour of such grain is presumed to be more acceptable for blending with wheat flour. A recent low-key initiative to introgress this grain color in the elite and adapted genetic backgrounds led to the production and

evaluation of 110 progenies, most of which were late, flowering in more than 65 days. Sixteen progenies were selected (two of these flowering in 51–60 days), primarily based on white grain color, that produced 32 F<sub>4</sub> progenies, which were further evaluated during the 2007 rainy season, of which 6 were selected based on visual assessment for agronomic performance and also for enhanced levels of white grain color. Five of the selected progenies flowered in 51–65 days and one progeny was very late (checks ICMB 94222 and ICMV 221 flowered in 41 days).

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*Milestone 5A.2.1.2: Genetically diverse trait-specific (eg., large seed, large panicle size, diverse maturity and height) advanced breeding lines developed and disseminated (KNR/RB/RPT/RS, 2006, 2008, 2010, 2012)*

The primary objective of pearl millet breeding at ICRISAT is to develop improved lines with high grain yields and high levels of DM resistance. There is also considerable emphasis on selecting lines having certain specific traits, including plant types of the parental lines of some of the commercial hybrids. This is a requirement of the users of these improved germplasm both in the public and the private sector hybrid breeding. Therefore, the improved breeding lines that are mostly at the later stages of inbreeding are classified and evaluated in trait-specific nurseries for better evaluation and selection for future utilization. These trait-specific nurseries are updated constantly with new materials that are generated almost every year.

#### **Trait-specific seed parent progenies**

**Early-maturing progenies:** We evaluated 178-advanced generation progenies (S<sub>8</sub>/S<sub>12</sub>/F<sub>8</sub>), of which 127 progenies were selected based on visual assessment of agronomic traits, yield potential and early maturity. Of these, 70 progenies flowered within 40 days, 33 in 41–45 days and 24 progenies flowered in 46–55 days (checks 843B flowered in 37 days and 842B in 44 days). In addition, we also evaluated 276 B×B F<sub>5</sub> progenies (EEBC/EEDBC/843B/97444 type early progenies), of which 139 progenies were selected based on earliness and visual assessment of yield potential and agronomic traits. Of these, 32 progenies flowered within 40 days and the remaining 107 progenies flowered in 41–50 days (checks 843B flowered in 36 days and 842B in 42 days). In addition, the parents and resultant 513 top-cross F<sub>3</sub> progenies from random-mated early B-lines were also evaluated during the 2007 rainy season. About 190 progenies were selected based on visual assessment for agronomic performance and earliness, of which 45% of the progenies flowered within 40 days and the remaining 108 progenies flowered in 41–50 days (checks 843B flowered in 36 days and 842B in 42 days).

The 276 B×B F<sub>5</sub> progenies were evaluated for resistance to Durgapura and Jalna pathotype under high disease pressure in the greenhouse (susceptible checks 7042S and ICMP 451 had more than 90% disease incidence). Of these, 68 progenies were highly resistant (with less than 10% DM incidence) to both the pathotypes, and another 32 progenies had 11–20% DM incidence.

**Large-seeded progenies:** About 195 advanced generation (F<sub>6</sub> onwards) progenies were evaluated, of which about 100 were selected based on visual assessment for large seed and agronomic traits. Of these, 73 progenies flowered in 46–55 days (ICMB 00444 flowered in 45 days). There were five progenies that flowered in 40–45 days.

**Long-panicle progenies:** We evaluated 837 progenies (S<sub>3</sub>/F<sub>5</sub>/F<sub>6</sub>), of which 260 progenies were selected. Of these, 82 progenies flowered in 56–65 days and 176 progenies flowered in 46–55 days (checks 81B and ICMB 04111 flowered in 52 and 55 days, respectively). There were 2 progenies that flowered in 40–45 days.

**Thick-panicle progenies:** We evaluated 201 advanced generation progenies (S<sub>6</sub>/S<sub>7</sub>/F<sub>14</sub> onward), of which 118 were selected based on visual assessment for panicle thickness and agronomic performance. Of these, 57 progenies flowered in 46–55 days and the remaining 61 progenies flowered in 56–65 days (HHVDBC, the dwarf population with very thick panicles and flowered in 52 days). We also evaluated 92 F<sub>1</sub> progenies derived from crosses between thick head and early progenies, of which 69 were selected based on their earliness, panicle thickness and agronomic performance. Of these, 61 progenies flowered in 41–50 days and 8 flowered within 40 days.

**Stay-green lines:** At 120 days after planting (40–45 days after physiological maturity), 109 seed-parent progenies were identified from 20 different nurseries with days to flowering ranging from 40–65 days. Of these,

23% progenies flowered within 45 days and based on visual assessment for agronomic performance, 46% progenies had a high score (4-5) on 1-5 scale.

**Other traits:** Besides the above traits of primary breeding significance, there are other traits, which are important in breeding and should be combined with the primary traits for evaluation. These traits are useful genetic resources for introgression into elite breeding lines. Thus, improved breeding lines with very dwarf plant height (45-80 cm tall, but 30-50% of this being the panicle length), compact panicles, and erect growth habit have been developed.

We evaluated 34 advanced generation  $d_2$  dwarf progenies ( $F_{10}$  and beyond) and all the progenies were selected based on agronomic traits and yield potential, with 23 of these flowering in 41-50 days, 9 in 51-65 days and 2 progenies flowering within 40 days (ICMB 96555 flowered in 45 days). Similarly, we evaluated 490 early generation very dwarf progenies ( $F_4/F_3$ ), of which 59 were selected based on visual assessment of agronomic traits with 52 of these flowering in 46-55 days and 2 progenies in 41-45 days (check ICMB 96555 flowered in 43 days). We also evaluated 325 early generation bristled progenies ( $F_3$ ), of which 136 were selected based on visual assessment for agronomic performance and presence of bristles. Of these, 128 progenies flowered in 46-55 days and 4 flowered in 56-60 days (check 81B flowered in 51 days and 2035 Br. flowered in 64 days). There were 4 progenies that flowered in 41-45 days.

**Specific seed parent-type progenies:** We evaluated 22 advanced generation progenies ( $F_{10}$  and beyond) resembling the broad morphological frames of most popular commercial seed parent, 81B, of which 20 progenies were selected with 18 of these flowering in 46-55 days and 2 flowering in 56-60 days (checks 81B flowered in 52 days). Similarly, we evaluated 48 advanced generation ( $F_8/S_8$ )  $NCD_2$  progenies, of which 35 progenies were selected with 31 of these flowering in 51-60 days and 4 progenies flowering in 61-65 days (check  $NCD_2$  flowered in 50 days and 81B flowered in 52 days).

#### **Trait-specific restorer progenies**

A similar approach of trait-based restorer parents has also been initiated in a restorer development program for comparative evaluation of breeding lines and their utilization in breeding programs both at ICRISAT and in the NARS and the private sector breeding programs. The trait-based approach is also being followed to develop breeding lines that may be adapted to very contrasting agro-ecoregions.

**Large-seeded progenies:** During 2006, four advanced generation progenies ( $S_8$ - $S_9$ ) progenies were selected and this large-seeded nursery was further upgraded with 41 progenies ( $S_4$ - $S_{10}$ ) from various other restorer parent nurseries, of which 27 progenies ( $S_5$ - $S_{11}$ ) were selected in the 2006 rainy season. These progenies were further evaluated during the 2007 postrainy season, of which 11 were selected based on agronomic performance and seed-size with 8 of these flowering in 51-60 days and 3 flowering in 46-50 days.

**High-tillering progenies:** We evaluated 127 progenies ( $S_4$ - $S_{12}$ ) during the 2007 postrainy season, of which 47 were selected with 33 of these flowering in 51-60 days and 5 flowering in 61-65 days (check ICMR 356 flowered in 46 days). There were 9 progenies that flowered in 46-50 days.

**Thick panicle progenies:** The selected 38 progenies ( $S_4$ - $S_{11}$ ) from the 2006 rainy season were further evaluated during the 2007 postrainy season, of which 16 were selected based on visual assessment for agronomic performance. Of these, 14 progenies flowered in 51-60 days and 2 flowered in 46-50 days (check IPC 1518 flowered in 46 days).

**Compact panicle progenies:** We evaluated 81 progenies ( $S_4$ - $S_{12}$ ) selected during the 2006 rainy season for their agronomic performance and panicle compactness during the 2007 postrainy season. Of these, 46 progenies were selected with 15 progenies flowering in 56-65 days and the remaining 31 progenies flowering in 46-55 days (check ICMP 451 flowered in 48 days and IPC 1518 flowered in 46 days).

**Extra-early and Early-maturing progenies:** The restorer parents used in the hybrid breeding program are mostly of medium to mid-late in maturity and are used for breeding restorers of dual-purpose hybrids. Based on the demand from user programs both in the public and the private sector for early-maturing restorers, a major initiative has recently been undertaken to breed early-maturing restorer lines. We evaluated about 200 progenies

(S<sub>4</sub> S<sub>13</sub>) during the 2007 postrainy season, of which 70 progenies were selected with 63 progenies flowering in 46–55 days and 4 progenies flowering in 56–60 days (checks EEBC 407 flowered in 42 days and ICMR 356 in 49 days). There were 3 progenies that flowered in 40–45 days. We also evaluated about 200 early-maturing advance generation progenies (S<sub>5</sub> S<sub>14</sub>) in a breeding nursery during the 2007 rainy season, of which 110 were selected based on their agronomic performance and earliness. Of these, about 105 progenies flowered in 41–50 days and 2 flowered within 40 days (checks EEBC 407 flowered in 38 days and H 77/833-2 flowered in 42 days). Similarly, about 495 F<sub>3</sub> progenies derived from extra-early composite crosses were evaluated during the 2007 rainy season, of which 225 were selected with about 200 progenies flowering in 41–50 days and 20 progenies flowering within 40 days (check EEBC 407 flowered in 37 days and ICMR 356 flowered in 42 days).

**Dual-purpose progenies:** We evaluated 33 progenies (S<sub>5</sub> S<sub>12</sub>) during the 2007 postrainy season, of which 11 were selected based on agronomic performance for grain and stover yield. Of these, 9 progenies flowered in 51–60 days and 2 in 61–65 days (check ICMP 451 flowered in 49 days).

**Stay-green lines:** About 40 advance generation stay-green progenies (S<sub>8</sub> S<sub>12</sub>) were evaluated during the 2007 postrainy season for agronomic traits and more specifically for expression of stay-green traits under drought conditions. Based on visual assessment for agronomic performance, 10 progenies were selected with 9 of these flowering in 51–60 days and 1 flowering in 61–65 days (check ICMR 356 flowered in 46 days and ICMP 451 in 48 days). Similarly, about 190 progenies (S<sub>3</sub> S<sub>13</sub>) were evaluated in the breeding nursery under drought conditions during the 2007 postrainy season, of which 93 progenies were selected based on agronomic performance and stay-green traits. Of these, 60 progenies flowered in 46–55 days and 26 in 56–65 days (check ICMP 451 flowered in 54 days and IPC 1518 in 48 days). There were 5 progenies that flowered in 41–45 days and 2 progenies that flowered within 40 days.

At 120 days after planting (physiological maturity at 75–80 days), 93 restorer progenies were identified from 15 different nurseries with days to flowering ranging from 39–69 days. Of these 20% progenies flowered within 45 days and based on visual assessment of agronomic performance, 78% progenies scored high (4-5) on 1–5 scale for stay-green trait.

**Other traits:** As in the seed parents breeding program, there are secondary traits in restorer progenies that add value to the breeding materials. These traits are: lodging resistance and erect growth habit. Thus, 15 progenies (S<sub>4</sub> S<sub>12</sub>) were tested in the postrainy season for lodging resistance, of which 6 were selected based on visual assessment for agronomic performance and lodging resistance, with all of these flowering in 51–60 days (checks ICMR 356 and ICMP 451 flowered in 46 days). We also evaluated 47 advanced generation progenies (S<sub>5</sub> S<sub>11</sub>) for erect growth habit, of which 21 were selected, with 15 of these flowering in 51–60 days and 4 progenies flowering in 46–50 days (check IPC 804 flowered in 48 days).

About 1425 advance generation progenies from different trait-specific groups (high-tillering, early maturing, dual purpose, stay-green types, etc.) were screened against Durgapura pathotype under greenhouse conditions with heavy disease pressure (more than 98% disease incidence in checks 7042S and ICMP 451). Of these, about 610 progenies showed less than 10% disease incidence and 167 progenies showed 11–20% disease incidence. Similarly, about 290 progenies from different trait-specific groups were screened against Jalna pathotype under heavy disease pressure (more than 98% disease incidence in susceptible checks 7042S and ICMP 451), of which 130 progenies showed less than 10% disease incidence and 40 progenies showed 11–20% disease incidence.

**Specific restorer-type progenies:** The parental lines of commercial hybrids or the lines identified as good general combiner and with farmer-preferred traits become reference lines among users of ICRISAT-bred lines. For this purpose, we evaluated about 45 ICMR 356 type progenies (S<sub>4</sub> S<sub>12</sub>) during the 2007 postrainy season, of which 20 were selected based on visual assessment of agronomic performance and plant type. Of these, 18 progenies flowered in 46–55 days and 2 progenies flowered in 40–45 days (check ICMR 356 flowered in 44 days). Similarly, we also evaluated 90 IPC 804-type progenies (S<sub>5</sub> S<sub>12</sub>) during the postrainy season. Based on visual assessment for agronomic performance and plant type, 33 progenies were selected, of which 25 flowered in 46–55 days and 7 flowered in 56–65 days (check IPC 804 flowered in 48 days). Another 190 progenies of high agronomic score were evaluated during the postrainy season, of which 74 were selected with 55 progenies flowering in 51–60 days and 10 progenies in 61–65 days (checks ICMR 356 flowered in 42 days, IPC 804

flowered in 42 days and ICMP 451 flowered in 42 days). There were nine progenies that flowered in 46–50 days.

**Restorer parent progenies with specific agro-ecological adaptation:** In India, western Rajasthan (arid) and Maharashtra (semi-arid) represent the two most contrasting agro-ecological regions. Thus, for Rajasthan adaptation (largely high-tillering type with small to medium seed size), we evaluated 57 advanced generation ( $S_7$ – $S_{12}$ ) progenies, of which 14 were selected, with 13 of these flowering in 46–55 days and one progeny flowering in 56–60 days (checks H 77/833-2 flowered in 41 days and ICMR 356 in 52 days). Similarly, MRC-derived progenies were also identified as Rajasthan-adapted type and about 50 advanced generation ( $S_8$ / $S_{10}$ ) progenies were evaluated, of which 40 were selected with 27 progenies flowering in 46–55 days and 13 progenies flowering in 40–45 days. For Maharashtra adaptation (mostly *iniadi* type with dark grey color and medium to large grains), we evaluated 16 advanced generation progenies ( $S_7$ – $S_{12}$ ), of which 8 were selected, with 7 of these flowering in 51–60 days (check ICTP 8203 flowered in 46 days) and one progeny flowered in 46–50 days.

#### **Genetic diversification of restorer lines**

As in the seed parent breeding program, evaluation of restorer parent progenies is also done by planting them according to their parentage during the initial stage of inbreeding and selection. These materials are carried forward in similar fashion, but these are included in the trait-specific groups for final evaluation mostly at  $F_5$ / $S_5$  and beyond. These early and advanced generation progenies are:

**Early-generation progenies ( $S_1$ – $S_3$ ):** This consisted of *iniadi* type progenies ( $S_1$ / $S_2$ ) from ICTP 8202 and LaGrap, and dual-purpose progenies from seven populations. We evaluated about 120 progenies of ICTP 8202 in the post-rainy season drought nursery, of which 82 were selected based on agronomic performance, with 74 of these flowering in 46–55 days and 8 flowering in 41–45 days (check ICMR 356 flowered in 48 days). In LaGrap, we evaluated 161 progenies ( $S_3$ ) during the rainy season, of which 28 were selected with 21 of these flowering in 40–45 days and 7 flowering in 46–50 days (check ICMP 451 flowered in 49 days). In the dual-purpose group, we evaluated 458  $S_1$ / $S_5$  progenies derived from 10 populations (including OPVs), of which 203 were selected, with 111 of these flowering in 46–55 days and 89 flowering in 56–65 days (checks ICMP 451 flowered in 48 days and HTP 94/54 flowered in 49 days). There were 2 progenies that flowered in 41–45 days. All the 500 JBV 3  $S_5$  progenies were screened against Durgapura pathotype under glasshouse condition with heavy disease pressure (susceptible checks 7042S and ICMP 451 had more than 98% disease incidences). Of these, 144 progenies were selected with 35% of the progenies showing less than 10% disease incidence and 33% progenies showing 11–20% disease incidence.

**Advanced generation progenies ( $S_7$ – $S_{11}$ ):** This also consisted of both *iniadi* type progenies derived from GB 8735 and non-*iniadi* type progenies from four OPVs. Of the 66 progenies derived from GB 8735 and evaluated in the 2007 post-rainy season, 33 were selected with 20 of these flowering in 51–60 days and 7 flowering in 40–50 days (checks ICMR 356 flowered in 47 days and IPC 1518 in 48 days). In the dual-purpose group, we evaluated about 300  $S_7$ / $S_{11}$  progenies, of which 95 progenies were selected, with 59 of these flowering in 46–50 days and 39 flowering in 51–60 days (checks ICMP 451 flowered in 47 days and HTP 94/54 in 49 days). Similarly, in the dual-purpose group, we evaluated 492  $S_5$  JBV 3 progenies, of which 144 were selected, with 121 of these flowering in 46–55 days and 14 flowering in 56–60 days. There were 9 progenies that flowered in 41–45 days.

**$A_5$  restorer development:** 46  $F_4$  progenies derived from 6  $F_2$  populations in the cytoplasmic background of the  $A_5$  and having the  $A_5$  restorer gene(s) were evaluated, of which 30 were selected based on the visual assessment of agronomic traits. In addition, 141  $F_3$  progenies were generated from fertile  $F_1$  plants that had been produced by crossing elite inbred lines on fertile plants of 8 initial  $F_2$  populations, of which 110 progenies flowered in 51–60 days and 31 flowered in 40–50 days (checks ICMP 451 and IPC 1518 flowered in 46 days).

We also evaluated 170  $F_4$  progenies derived from two  $F_2$  populations (IPC 1617–SDMV 90031- $S_1$ -84-1-1-1-1 and IPC107–ICMV 91059  $S_1$ -14-2-1-1-2) with  $A_5$  cytoplasmic background and having  $A_5$  restorer gene(s) with resistance to Durgapura pathotype during the post-rainy season, from which 101 progenies were selected with 89 progenies flowering in 46–55 days and 11 progenies in 56–60 days (checks ICMR 356 flowered in 53 days and ICMP 451 in 54 days). Additionally, another set of 357 advanced generation progenies ( $F_6$ ) were

evaluated during the rainy season, of which 80 were selected with 58 flowering in 46–55 days and 20 flowering in 56–60 days (checks ICMP 451 and IPC 1518 flowered in 46 days). There were two progenies that flowered in 40–45 days.

All the 475 A<sub>5</sub> restorer progenies (F<sub>4</sub>) were screened against Durgapura pathotype under glasshouse conditions with heavy disease pressure (susceptible checks 7042S and ICMP 451 had more than 94% disease incidence). Of these about 140 progenies showed less than 10% disease incidence and 101 progenies showed 11–20% disease incidence. Similarly, about 400 progenies (F<sub>4</sub>/F<sub>5</sub>) were also screened against Durgapura pathotype with about 63% of them showing less than 10% disease incidence and 11% showing 11–20% disease incidence.

**Restorer parents derived from population intercrosses:** To increase panicle length in RIB 3135-18 and MRC type progenies, and for inducing earliness, tillering and correcting exertion in long panicle types, a crossing program was undertaken. A total of 511 progenies (F<sub>6</sub>–F<sub>9</sub>), of which 53 progenies belonging to RIB 3135-18 × long spike, 335 to MRC × long spike and 123 to RCB × MRC progenies were evaluated during 2007 rainy season. Of these, 138 were selected with 44% progenies flowering in 51–55 days and 31% flowering in 40–50 days (check RIB 3135-18 flowered in 47 days and ICMR 356 in 46 days). Similarly, about 805 dual purpose progenies (F<sub>3</sub>/F<sub>7</sub>) were evaluated during the rainy season, of which 611 progenies belonged to restorer × restorer crosses (F<sub>3</sub>) and 196 belonged to ICMS 7704 × RCB 2 (F<sub>7</sub>) progenies. About 170 progenies were selected with 53% of the progenies flowering in 51–55 days and 14% flowering in 40–50 days (check ICMR 356 flowered in 46 days and ICMP 451 in 49 days).

The downy mildew screening of these population intercrosses against Durgapura pathotype under glasshouse conditions with heavy disease pressure (susceptible checks 7042S and ICMP 451 had 100% disease incidence) showed that 7 progenies of RIB 3135 × long panicle progenies had less than 10% disease incidence. Similarly, 6 progenies of RCB × MRC cross and 16 progenies of 7704 × RCB cross had less than 10% disease incidence, respectively.

**Crosses involving restorer parents:** With the objective of getting earliness, good tillering, compact panicles with good exertion and large seed, a crossing program was undertaken during the 2007 post-rainy season involving elite restorer lines. The resulting 207 crosses were evaluated in a hybrid observation nursery during the rainy season, of which 83 were selected based on visual assessment for agronomic traits with 64 of these flowering in 40–50 days and 16 flowering in 51–55 days (checks ICMR 356 flowered in 45 days and ICMP 451 flowered in 48 days). There was one F<sub>2</sub> population that flowered within 40 days.

**Fertility/Sterility reaction of elite testcrosses:** About 235 advanced generation restorer lines were tested for fertility/sterility reaction with four male-sterile lines (ICMA 96222 A<sub>1</sub>, ICMA 97333 A<sub>1</sub>, ICMA 01222 A<sub>4</sub> and ICMA 021111 A<sub>4</sub>). Of these, 55 lines showed fertility reaction on both A<sub>1</sub>-system male-sterile lines, 33 lines on both A<sub>4</sub>-system male-sterile lines and 27 lines showed fertility reaction on all the four male-sterile lines.

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*Milestone 5A.2.1.3: An elite B-composite and an elite R-composite with resistance to multiple pathotypes of downy mildew populations developed (KNR/RB/RPT/RS, 2009)*

Three hundred and sixty two potential restorer progenies were screened in 1 pot/entry against the most virulent DM pathotype from Banaskantha, Gujarat (India) leading to the identification of 105 resistant progenies. These were tested along with two controls in 2 pots, replicated twice with the same pathotype. Fifty-three progenies were found to be resistant which were further screened against four other virulent pathotypes (Barmer, Jamnagar, Jodhpur and Jalna) along with five controls under greenhouse conditions with high disease pressure (susceptible checks 7042S and ICMP 451 had more than 98% disease incidence against all the five pathotypes) with an objective to constitute a multiple pathotype resistant R-composite. Of these, 11 progenies were resistant (0–10% disease incidence) to all the five pathotypes and 7 progenies were resistant to four out of five pathotypes with 0–10% disease incidence. There were five progenies with 11–20% disease incidence against all the five pathotypes. Similarly, a resistant B-composite will be constituted by screening elite B-lines against these virulent and diverse pathotypes.

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*MTP Output target 5A.3: Morphological and molecular diversity of more than 150 elite inbred lines of pearl millet assessed and the relationship between diversity and yield heterosis demonstrated (2009)*

### **Activity 5A 3.1: Evaluate parental lines, advanced breeding lines and their hybrids for grain yield, and morphological and molecular diversity**

*Milestone 5A.3.1.1: Designated seed parents and restorer lines characterized for DUS traits and molecular diversity (KNR/RB/VV, 2008)*

*MTP Output Target 2007 5.1.1 PM*

*More than 150 potential hybrid parents characterized for morphological diversity*

**Characterization for DUS traits:** Two-season characterization data of 99 A/B pairs (1981 to 2004-series A/B pairs) for 26 morphological traits (recorded following DUS guidelines) from a replicated trial was compiled for documentation. The key characteristics of each A/B pair along with their photographs have also been completed. In order to document the designated restorer lines, about 120 lines were characterized for 26 DUS traits from a replicated trial during the rainy season. The data are yet to be computerized and the second-season characterization will be carried out during the 2008 postrainy season.

DNA was extracted from 127 B-lines and 147 R-lines and a working concentration of 2.5ng/  $\mu$ l was prepared. PCR optimization for 20 SSR markers was done following Taguchi method. PCR products are ready and will be run through ABI 3100 to get the allelic peaks, which will be further run through GeneScan and Genotyper software to generate information on alleles per SSR marker.

**Morphological diversity in designated seed parental lines:** Ninety-nine designated cytoplasmic male-sterile (A) lines along with their maintainer (B) lines in three different CMS backgrounds viz., A<sub>1</sub> (63), A<sub>4</sub> (35) and A<sub>egp</sub> (1) were characterized in a replicated trial for 26 morphological traits (including 17 essential traits) following DUS guidelines during the 2005 summer and rainy season.

The cluster analysis based on 10 quantitative traits grouped 99 maintainer lines into two major clusters at 20% dissimilarity coefficient with ICMB 04111 and ICMB 04777 clustering together in a distinct cluster and the remaining clustering in the second cluster. However, at 9% dissimilarity level, the inbred lines clustered into 8 distinct groups and this has relevance to the respective parentage of these lines. All the lines that grouped in a cluster were similar either by parentage or they were of similar maturity. Some of the lines with similar parentage also grouped in different clusters, which is mainly due to differences in their maturity or plant height. The principal component analysis showed that days to 50% flowering, plant height, spike length and seed weight contributed about 67.3% of the variation present between these 99 B-lines with days to 50% flowering ranging between 41 and 60 days, plant height between 62 to 136 cm, spike length between 12 to 35 cm and 1000-grain weight between 7 to 13 g.

The molecular diversity will be assessed once the genotyping is completed on these lines using 20 SSR markers.

**Within-line diversity:** To assess the within line genetic variation, ten phenotypically diverse B- and 10 R-lines were planted during the rainy season and 40 selfed plants were randomly selected from each line and harvested separately. These will be planted again individually during the 2008 postrainy season for morphological characterization and genotyping with 20 SSR markers.

KN Rai and Ranjana Bhattacharjee

*Milestone 5A.3.1.2: Selected hybrid parents and advanced breeding lines characterized for morphological and molecular diversity, and yield heterosis (KNR/RB/CTH, 2009)*

Trait-based breeding in pearl millet at ICRISAT-Patancheru has apparently been quite successful in developing and disseminating a diverse range of designated hybrid parents (seed parents and restorers) and advanced breeding lines that have led to the diversification of the NARS and private sector breeding programs, and commercialization of more than 70 hybrids in India. However, no efforts were made to generate quantified information on these designated parental lines. An attempt has been therefore made to generate data on 26 morphological characteristics (based on DUS guidelines) for which two-season data from replicated trials have been generated. These parental lines are also being subjected to finer fingerprinting to provide additional information useful for IPR protection. This will enable further enhancement of the breeding efficiency and preparing for IPR protection of some of the most promising breeding products. The first issue is related to the molecular marker-based diversity analysis of designated hybrid parents and comparison of the genotypic

diversity with diversity based on morphological traits. The second issue is related to the evaluation of the relationship between molecular diversity and heterosis for grain and stover yield. This information will therefore provide a foundation to undertake classification of a diverse range of hybrid parents and advanced breeding lines into heterotic groups, which will eventually enhance the efficiency of breeding both hybrids and hybrid parents.

KN Rai and Ranjana Bhattacharjee

*Milestone 5A.3.1.3: Two medium-maturity heterotic gene pools based on molecular marker diversity constituted (KNR/RB/SC/RV, 2012)*

(Not initiated)

**Output target 5A.4: QTL for downy mildew resistance in pearl millet identified, compared to those previously detected, and their effect on DM resistance assessed (2008)**

**Activity 5A.4.1: Development of mapping populations and QTL mapping of DM resistance**

*Milestone 5A.4.1.1: QTL mapping based on  $F_6$  RILs and  $F_{2:4}$  progenies from two crosses completed and results compared (CTH/SS/RPT/RS, 2008)*

*Milestone 5A.4.1.2: Genetically diverse parents of mapping population parents identified and crossed to generate  $F_6$  RILs (CTH/KNR/RPT/RS, 2007)*

Elite parents and plant-to-plant crosses were evaluated in 3 replications, 2 pot/replication against Durgapura (Sg 212), Ahmadnagar (Sg 21), Jamnagar (Sg 200) and Patancheru (Sg 409) pathotypes in the greenhouse for DM resistance. Ninety seven parents and crosses were screened against Durgapura, 74 against Ahmadnagar, 79 against Jamnagar and 16 against Patancheru pathotype. Sixty-six crosses and parents were found resistant to Durgapura, 40 to Ahmadnagar, 28 to Jamnagar and 7 to Patancheru pathotype.

RP Thakur, Rajan Sharma and CT Hash

**Activity 5A.4.2: Map-directed conventional backcrossing and marker-assisted backcrossing of DM resistance QTL into parental lines of hybrids**

*Milestone 5A.4.2.1: Ten major QTL imparting resistance against specific DM pathotypes identified (CTH/RPT/RS, 2007)*

As funds for the 2007/08 cropping season have not yet (as of December 2007) been released to ICRISAT by the Indian Council of Agricultural Research (ICAR), there have not been any operational funds available to cover the cost of greenhouse downy mildew screening of newly finished RIL population progeny sets following their multiplication during the 2006/07 post-rainy season (seed multiplication and DNA sample preparation costs were met from funds released by ICAR for 2006/07). Therefore it has not been possible to generate the phenotyping data required for mapping the host plant resistance QTLs from the newly available advanced-generation RIL populations to meet this milestone.

CT Hash, T Nepolean, RP Thakur and R Sharma

*Milestone 5A.4.2.2: Near-isogenic lines containing different DM resistance genes (QTL) developed (RPT/RS/CTH, 2010)*

Near-isogenic lines with different resistance genes in the same genetic background have been used as host differential to study pathogenic variation in several host-pathogen systems. We are developing near isogenic lines in the genetic background of 81B and 843B for different QTLs of known effect against diverse pathotypes of *S. graminicola* that can be used as host differentials to characterize different pathotypes of pearl millet downy mildew.

**Evaluation of 81B and 843B-like derivatives of donor parent, IP 18293 and P 1449-2 for downy mildew resistance:** One hundred fifty-four 81B-like and 147 843B-like derivatives from backcross progenies from IP 18293 as a donor parent and 202 843B-like derivatives from P 1449-2 were evaluated in 3 replications, 1 pot/replication against Barmer pathotype (Sg 384) in the greenhouse. None of the derivatives from IP 18293 was



found resistant, however, five 843B-like derivatives from P 1449-2 were resistant ( $\leq 10\%$  incidence) compared to 93% incidence on 843B and 91% on 81B, and 59% on IP 18293.

**Evaluation of 843B-like derivatives of donor parent, P 1449-2 for downy mildew resistance:** Three hundred fifty six 843B-like derivatives including original parents from BC<sub>4</sub>F<sub>1</sub>/BC<sub>3</sub>F<sub>2</sub> backcross progenies from P 1449-2 as a donor parent were evaluated in 3 replications, 1 pot/replication against New Delhi pathotype (Sg 298) in the greenhouse. Of the 278 843B-like derivatives, 82 (29%) were resistant ( $\leq 10\%$  incidence) compared with 84% incidence on 843B and 4% on P 1449-2. Similarly, 81B-like and 843B-like derivatives from backcross progenies from other donor parents will be evaluated against different pathotypes to develop near isogenic lines with different QTLs for DM resistance.

CT Hash, RP Thakur and Rajan Sharma

*Milestone 5A.4.2.3: QTLs with known effects against diverse pathotypes pyramided in 843B and other parental lines and their resistance level determined (CTH/RPT/RS, 2010)*

Several QTLs for DM resistance have been identified against diverse pathotypes of DM pathogen. QTLs with known effect against diverse pathotypes can be pyramided in elite seed parent lines for enhanced DM resistance.

**Evaluation of 841B-like derivatives of donor parent 863B for downy mildew resistance:** Seventy-one 841B-like derivatives including original parents from backcross progenies from 863B as a donor parent were evaluated in 3 replications, 1 pot/replication against Barmer pathotype (Sg 384) in the greenhouse. Of 71 841B-like derivatives, 34 (48%) were resistant ( $\leq 10\%$  incidence) compared with 93% incidence on 843B and 21% on 863B.

**Evaluation of HMS 7B-like derivatives of donor parents, 863B and P 1449-2 for downy mildew resistance:** Nineteen HMS 7B-like derivatives including original parents from backcross progenies from 863B and sixteen HMS 7B-like derivatives from P 1449-2 as a donor parent were evaluated in 3 replications, 1 pot/replication against Barmer pathotype (Sg 384) in the greenhouse. Only one HMS 7B-like derivative from 863B was found resistant to Barmer pathotype.

RP Thakur, Rajan Sharma and CT Hash

*Milestone 5A.4.2.4: Several different single-QTL introgression homozygotes available in genetic backgrounds of two elite seed parents (CTH/RPT/RS, 2007)*

QTL introgression homozygotes in 81B and 843B backgrounds were to have been identified by greenhouse screening of backcross F<sub>2</sub> populations (to reduce the number of plants to be genotyped) followed by SSR marker genotyping of disease-free seedlings following their transplanting to the breeding nursery. However, the greenhouse screening failed, apparently due to high temperatures, so achievement of this milestone will be delayed to 2008.

CT Hash, T Nepolean, RP Thakur and R Sharma

*Milestone 5A.4.2.5: Several different multiple-QTL introgression homozygotes available in genetic backgrounds of an elite restorer line and three diverse elite seed parents (CTH/TN/SS/RPT/RS, 2009)*

Progress toward this milestone was made, or not, as indicated above for milestones 5A.4.2.1, 5A.4.2.2, 5A.4.2.3, and 5A.4.2.4.

CT Hash, T Nepolean, S Senthilvel,  
RP Thakur and R Sharma

#### **Output target 5A.5: Virulence changes in pearl millet DM pathogen populations determined (2009)**

##### **Activity 5A.5.1: Conduct field and laboratory studies to monitor the nature of virulence change in DM pathogen populations**

*Milestone 5A.5.1.1: Ten to fifteen DM isolates each from Gujarat, Rajasthan, Maharashtra and Uttar Pradesh characterized for pathogenicity and virulence (RPT/RS/KNR/RB, 2008)*

**Characterization of isolates of *Sclerospora graminicola* for pathogenicity and virulence:** Isolates collected from highly susceptible pearl millet cultivars during on-farm surveys are characterized for virulence diversity

and monitored for changes in virulence. Highly virulent isolates thus identified are used for screening breeding lines towards developing downy mildew resistant hybrid parental lines and hybrids. As of now we have collected 522 samples of *S. graminicola* inoculum from different pearl millet hybrids/lines in 10 states in India. Of these, during the past 5 years, we have characterized 59 isolates for pathogenicity and virulence from 7 states (Andhra Pradesh-16, Maharashtra-3, Gujarat-11, Rajasthan-25, Haryana-2, Karnataka-1, Delhi-1) using a set of host differentials under greenhouse conditions. Currently, 11 isolates/pathotypes (Sg 212, Sg 139, Sg 384, Sg 150, Sg 21, Sg 200, Sg 445, Sg 298, Sg 334, Sg 409 and Sg 48) are being used to screen breeding lines at ICRISAT.

During 2007, nine isolates of *Sclerospora graminicola* collected from 3 districts of eastern Rajasthan, India (5 from Jaipur, 3 from Dousa and 1 from Alwar) during on-farm surveys in the 2006 rainy season were established on ICMP 451 under greenhouse conditions at ICRISAT. The isolates were evaluated for virulence diversity using standard inoculation procedure onto 7 host differential lines (P 7-4, P 310-17, 700651, 7042R, 852B, IP 18292 and IP 18293) and two susceptible lines (ICMP 451 and 7042S) under greenhouse conditions. The experiment was conducted with 9 isolates, 9 pearl millet lines and 3 replications with 30-35 seedlings/replication in a Completely Randomized Design (CRD). The latent period<sub>50%</sub> was recorded from 4<sup>th</sup> day onwards after inoculation and disease incidence 2 weeks after inoculation. Based on latent period<sub>50%</sub> and disease incidence, virulence index (disease incidence × latent period<sup>-1</sup>) was calculated to measure the quantitative virulence of the isolates. ANOVA showed that there were significant variation in downy mildew incidence due to isolates, host genotypes and their interactions. Results indicated that Sg 457 from Sujanpura, Jaipur, was most virulent with mean downy mildew incidence of 93% across host differential lines followed by 77% by Sg 470 (Kaithun, Jaipur), 61% by Sg 462 (Naktighati, Jaipur). Isolate Sg 468 from Dousa district was the least virulent with mean downy mildew incidence of 26%. These three isolates from Jaipur were found virulent on all the 7 host differentials lines, whereas, populations from Dousa could cause >10% disease in 15 host differentials.

RP Thakur and Rajan Sharma

*Milestone 5A.5.1.2: Spatial and temporal virulence pattern of downy mildew pathogens assessed through virulence nursery and on-farm survey results (RPT/RS/KNR/RB/CTH, 2009)*

**Characterization of isolates:** Spatial and temporal variability among forty-six isolates of *Sclerospora graminicola* collected from seven states in India during 1992-2005 was determined through pathotyping and AFLP analysis. High level of variation was observed among the isolates for downy mildew incidence, latent period and virulence index. Based on the reaction on a set of 9 pearl millet lines, 46 isolates were classified in 21 pathotypes. Quantitative differences in virulence levels of the test isolates were assessed by calculating the virulence index (disease incidence × latent period<sup>-1</sup>). A dendrogram generated by the average linkage cluster analysis of virulence index clustered the 46 isolates into 8 groups. Region-specific grouping of 5 isolates from Gujarat and 6 from Rajasthan was observed within 2 distinct groups. Temporal variation was also observed among the isolates collected from the same location and the same host over the years. A total 297 bands were scored following selective amplification with 3 primer combinations E-TT/M-CAG, E-AT/M-CAG and E-TG/M-CAT and all of them were polymorphic. Cluster analysis of AFLP data clustered the test isolates into 7 groups. However, no association between grouping of the isolates based on molecular data and pathogenicity data could be established. Analysis of molecular variance indicated that variation in the *S. graminicola* populations was largely due to differences among the isolates within the states. There was no relationship between the clusters obtained from molecular and virulence index grouping.

Rajan Sharma and RP Thakur

**On-farm downy mildew survey:** Under the ICAR-ICRISAT partnership project, roving surveys were conducted in Gujarat and Uttar Pradesh (India) in collaboration with AICPMIP pathologists of the respective states and scientists from Pioneer Overseas Corporation during the summer and rainy seasons. In Gujarat, during summer, we surveyed 87 pearl millet fields in nine talukas of four districts (Gandhinagar, Mehasana, Banaskantha and Patan). Of the 87 fields, 7 (8%) fields had DM with a range of 11 to 81% incidence in Banaskantha. However, there was no downy mildew in other three districts (Gandhinagar, Mehasana and Patan). Of the 22 private sector hybrids (Arani 444, Bioseed 303, Great 555, Hanuman, JK Abhaya X-10, Kaveri-Boss, Kisan 851, MCH 5141, NK 1616, Pioneer 7777, -85M34, -86M52, -86M64, Proagro 9444, -9555, SHB 9514, Swaminath 73, Vikram 5166, SBH 7173, Biogene 66, Nirmal 10 and Surya), only Pioneer 7777 had 11 to 81% incidence and the remaining were free from DM. Only one public sector hybrid, GHB 558 was observed DM-free.

In Uttar Pradesh, 56 pearl millet fields were surveyed in 12 talukas of 5 districts (Agra, Aligarh, Hathras, Etah and Mathura) during the rainy season. DM was observed in 48 fields with a range of 3 to 100% incidence. Among the districts, DM was quite severe in Hathras with 100% incidence in Pioneer 86M32 in all the 4 fields surveyed, followed by Mathura (61-92%) in 7 fields, Agra (0-100%) in 21 fields, Aligarh (0-93%) in 20 fields and Etah (0-25%) in the 4 fields surveyed. Twelve private sector hybrids (Alankar, GK 1044, HS 68, JKBH 26, Kanchan, Kaveri 456, Krishna, Nirmal 1651, PAC 931, Pioneer 86M32, Pioneer 86M52 and SBH 768) were observed in the farmers' fields, and no public sector hybrids was found in the areas surveyed. Most of the seed supplied to farmers were treated with metalaxyl; the treated seed lots were 1-2 years old as indicated on the seed packets available with farmers. Of the 12 private sector hybrids, only 4 (Kanchan, Nirmal 1651, PAC 931 and Pioneer 86M52) were DM-free. However, these hybrids were grown only in 1 or 2 fields in the 5 districts surveyed. Maximum area was under Pioneer 86M32 and the disease was observed in all the 26 fields, with a mean DM incidence of 49% and range of 3-100%. Mean DM incidence in the remaining hybrids was in the range of 2% (JKBH 26) to 68% (HS 68). Nineteen DM-infected leaf samples from 8 susceptible hybrids and 2 local cultivars were collected from different pearl millet growing areas during on-farm survey. The isolates are being established for further studies on variability in the virulence of pathogen populations.

Since only 5 districts of Uttar Pradesh could be surveyed in rainy season-2007, the on-farm DM survey should be taken up again in 2008 to cover the other pearl millet growing areas in the districts of Badaun, Etawah, Ferozabad and Moradabad, in addition to the above five districts.

RP Thakur and Rajan Sharma

**Pearl Millet Downy Mildew Virulence Nursery (PMDMVN):** The PMDMVN-2006, consisting of 25 test entries including 11 from ICRISAT and 14 from AICPMIP, Mandor, and two local checks (one resistant and one susceptible), was established at 11 locations - Durgapura, Jodhpur, Fatehpur Sekhawati, Hisar, Anand, Jamnagar, Dhule, Gwalior, Patancheru, Mysore and Coimbatore (all in India). Each entry was grown in 2 rows of 4 m length. Downy mildew incidence was recorded at 30-day and 60-day after emergence. In general, there was an increase in disease incidence from the pre-tillering stage to the soft-dough stage for most lines, except for highly resistant lines where it was marginal. The disease pressure, as indicated by the disease incidence on 7042S (at the soft-dough stage), was very good (75-100%) at all locations except 57% at Mandor. The variation in the pathogen populations was evident from the mean disease incidence levels at different locations. The pathogen population at Anand and Durgapura appeared more virulent and those at Dhule, Coimbatore and Hisar were least virulent. Pearl millet lines IP 18292 and IP 18293 continued to remain resistant across most locations. Similarly five entries (PMP 01, -05, -08, -10 and -4) from AICPMIP, Mandor were found resistant with  $\leq 10\%$  mean incidence across locations. Nine entries from AICPMIP (PMP 02, -03, -04, -06, -07, -09, -11, -22 and -13) and another eight entries (P 7-4, P 310-17, 700651, 7042R, 852B, 834B, 843B and ICMP 451) showed variable reactions at different locations.

RP Thakur and Rajan Sharma

**Integrated management of downy mildew using biocontrol and Apron as seed dressing agents:** Under the ICAR-ICRISAT collaborative project, we conducted a field experiment to study the efficacy of *Bacillus pumulis* (INR 7) as a biocontrol agent in managing pearl millet downy mildew. The experiment was conducted in a completely randomized block design using 1 genotype (HHB 67)  $\times$  4 treatments- biocontrol alone, biocontrol + half dose of fungicide (Apron 35 SD @ 3 g Kg<sup>-1</sup> seed), Apron 35 SD @ 6 g Kg<sup>-1</sup> seed and untreated control  $\times$  6 replications, 2 rows of 4 m length/replication. Downy mildew incidence was recorded at 30-day and 60-day after emergence. The results indicated that *Bacillus pumulis* (INR 7) is equally effective as metalaxyl for managing downy mildew in pearl millet.

RP Thakur and Rajan Sharma

**Output target 5A.6: At least two improved populations and experimental hybrids of pearl millet with high forage yield potential developed (2009)**

**Activity 5A.6.1: Develop and evaluate improved open-pollinated varieties and hybrids for their forage yield potential**

*Milestone 5A.6.1.1: Additional germplasm sources with high biomass yield identified (KNR/RB/HDU/MB, 2009)*

Over the last few years, there has been an increased emphasis on developing hybrid parents or varieties with high forage yield potential. This has necessitated exploiting germplasm accessions of diverse origin with high

biomass yield. Fifty-two germplasm accessions from the pearl millet core collection were visually selected for high forage yield during the 2007 rainy season. Of these, 42% of the lines originated from Burkina Faso followed by 27% lines from Cameroon. There were four lines from Tanzania, two lines each from India and Mali, and one line each from Benin, Chad, Namibia, Nigeria, Senegal, Sudan, Togo and Zimbabwe, representing a wide range of material that has been selected for utilization in breeding program. All the selected germplasm accessions flowered in more than 90 days and the plant height ranged between 200 cm to 460 cm.

KN Rai, Ranjana Bhattacharjee and HD Upadhyaya

*Milestone 5A.6.1.2: Improved populations and experimental hybrids with high forage yield potential developed (KNR/RB/HDU/MB, 2009)*

Four OPVs developed for forage purposes have been evaluated during rainy and post-rainy seasons. Based on the mean performance across the two seasons, ICMV 05777 was found to be the highest yielding, giving 10.5 t ha<sup>-1</sup> of dry forage yield at 80-d harvest, which was comparable to that of the control (ICMA 00999 IP 17315). Another variety ICMV 05222 gave 9.3 t ha<sup>-1</sup> of the dry forage yield, which was 85% of that of the control (11.0 t ha<sup>-1</sup>). ICMV 05777 flowered in 71 days and ICMV 05222 in 64 days compared to 67 days for the control.

An experimental forage hybrid (ICMA 00999 IP 17315) earlier identified as the most promising, and consistently giving 15–30% more dry forage yield over the released forage hybrid Proagro 1, was used as a control in the forage trials. In a yield trial conducted during the 2007 rainy season, ICMV 06111, a promising forage variety gave 8.9 t ha<sup>-1</sup> of dry forage yield at 80-d harvest, which was 80% of the forage yield of ICMA 00999 IP 17315. ICMV 06111 flowered in 70 days compared to 67 days for ICMA 00999 IP 17315.

Twenty-three topcross hybrids produced by crossing eight forage type male-sterile lines with each of the five forage varieties were evaluated during the 2007 rainy and postrainy seasons for forage yield at 50 and 80-days harvest. Based on the mean performance over the two seasons, five hybrids (2 on ICMA 89111, 2 on ICMA 00999 and one on ICMA 90111) produced 11.1–13.6 t ha<sup>-1</sup> of dry forage yield (11.0 t ha<sup>-1</sup> for control hybrid, ICMA 00999 × IP 17315) at the 80-d harvest. All the selected hybrids flowered in 46–72 days (67 days for the check hybrid).

KN Rai, Ranjana Bhattacharjee and HD Upadhyaya

*Milestone 5A.6.1.3: Diverse seed parents with high forage yield potential developed and characterized (KNR/RB/MB, 2012)*

During the 2007 postrainy season, 21 seed parental lines from 8 different nurseries and 27 restorer lines from 9 different nurseries with the potential of producing high forage yield were selected. The days to flowering of the seed parental lines ranged from 42–58 days with 52% progenies flowering within 50 days. These lines will be further developed into seed parents to be used in breeding for high forage hybrids. Similarly, days to flowering of the restorer lines ranged from 42–68 days with 59% progenies flowering within 50 days.

KN Rai and Ranjana Bhattacharjee

**Output target 5A.7: Information on breeding efficiency and genetics of three diverse cytoplasmic-nuclear male-sterility (CMS) systems in pearl millet documented (2009)**

**Activity 5A.7.1: Documentation of research results related to CMS genetics and breeding efficiency in pearl millet**

*Milestone 5A.7.1.1: Comparative studies on efficiency of three diverse CMS systems completed (KNR, 2008)*

A comparison of A<sub>1</sub> CMS system with two additional CMS systems (A<sub>4</sub> and A<sub>5</sub>) based on isonuclear A-lines and isonuclear hybrids showed that A-lines with the A<sub>4</sub> cytoplasm had much fewer pollen shedders and much reduced selfed seed set in visually assessed non-shedding plants as compared to those with the A<sub>1</sub> cytoplasm. A-lines with the A<sub>5</sub> cytoplasm had neither any pollen shedders nor did they set any seed when selfed. This showed that the A<sub>5</sub> CMS system imparts complete and most stable male sterility, followed by the A<sub>4</sub> and A<sub>1</sub> CMS systems, in that order. The frequency of maintainers, averaged across a diverse range of 26 populations, was highest for the A<sub>5</sub> CMS system (98%), followed by the A<sub>4</sub> CMS system (59%) and the A<sub>1</sub> CMS system (34%), indicating the greatest prospects of genetic diversification of A-lines with the A<sub>5</sub> cytoplasm, and least with the A<sub>1</sub> cytoplasm. Mean grain yield of hybrids with the A<sub>1</sub> cytoplasm was 5% more than the A<sub>4</sub>-system hybrids,

while there was no difference between the mean grain yield of the A<sub>1</sub>-system hybrids and the A<sub>5</sub>-system hybrids. Based on these results, it is suggested that seed parents breeding efficiency will be greatest with the A<sub>5</sub> CMS system, followed by the A<sub>4</sub> CMS system, and least with the currently commercial A<sub>1</sub> CMS system.

KN Rai

*Milestone 5A.7.1.2: Genetical studies of diverse CMS systems completed (KNR/RB, 2009)*

(Draft paper under preparation)

**Output target 5A.8: Pearl millet technology exchange, capacity building and impact assessment undertaken and documented (2009)**

**Activity 5A.8.1: Enhance technology exchange and partnership building, and assess its impact**

*Milestone 5A.8.1.1: Seed of hybrid parents and breeding lines multiplied and distributed (KNR/RB, annual)*

We produced 1100 kg breeder seed of ICTP 8203 and 80 kg, 60 kg and 18 kg seed of three A-lines (ICMA 95222, ICMA 89111 and ICMA 95444) and 35 kg, 20 kg and 18 kg of their respective B-lines. We also produced 5 kg, 24 kg and 17 kg seed of IP 22269, bristled population and ICMH 356, respectively. Another 10 kg of seed was produced for early-maturity short height B-composite (3 kg) and early maturity medium height B-composite (7 kg).

In response to seed requests, 8515 seed samples were supplied to public and private organizations (1765 public and 6461 private) within India, and 289 samples of breeding materials supplied to about 4 countries abroad (Uzbekistan, Dubai, Mexico and Philippines). In addition, we supplied 569 kg seed of 12 lines (breeder seed) to 7 private sector companies and 8 public sector organizations.

As per the seed request, we also supplied 76 large seed samples (33 B lines, 3 R-lines, 3 hybrids, 7 composites, 14 improved populations and 16 germplasm accessions) along with a trial of 10 entries consisting of early-maturing populations to International Center for Biosaline Agriculture (ICBA), Dubai. Similarly, seeds of 11 entries for dual-purpose trial to be conducted at 18 locations, 13 entries of forage trial to be conducted at 10 locations, 10 entries of early maturing trial to be conducted at 10 locations and an unreplicated nursery of one composite and 3 populations for trial at farmer's fields were sent to Central Asia. Seed was also sent to Mexico that consisted of 10 entries of early maturing trial, unreplicated nursery of one variety, 5 A/B lines to make grain and forage hybrids, a nursery of forage population with 13 entries, dual purpose variety or population nursery with 18 entries and 50 entries of B- and R-line nursery.

*Milestone 5A.8.1.2: ICRISAT's partnerships with NARS, networks and regional fora strengthened (KNR/CLLG/pearl millet team, annual)*

Under the ICAR-ICRISAT partnership project, 13 trials (10 nurseries, one biofortification trial and two salinity trials) were constituted and sent to the AICPMIP coordinator for coordinating the evaluation at 14 locations. NARS scientists were increasingly involved in project development, joint publications, and facilitation of a research grant from DFID for DM resistance marker selection work and BMGF for drought tolerance in sorghum, pearl millet and finger millet.

ICRISAT-Private Sector partnership was further strengthened with 3 new seed companies joining Pearl Millet Hybrid Parents Consortium in 2007, taking it to a total of 37 consortium members.

The hybrid consortium trial, under the ICRISAT-private hybrid parents research consortium, consisted of 20 test hybrids from 11 private seed companies, which were evaluated during the rainy season at ICRISAT- Patancheru along with four controls (JKBH 676, HHB 67-2, ICMH 356 and 7688). The seed of the trial was also sent to eleven locations and the data from these locations are awaited. The data from trial at Patancheru showed that among checks, JKBH 676, a hybrid from JK Seeds, produced highest grain yield (5196 kg ha<sup>-1</sup>) and dry stover yield (4919 kg ha<sup>-1</sup>), and it flowered in 44 days. The hybrids that outperformed the best check, JKBH 676, in both grain and stover yield, were Bio 448 (4.2% higher grain yield and 24% higher stover yield) that flowered in 44 days, KDBH-2095 (2% higher grain yield and 35% higher stover yield) that flowered in 48 days and P-105 (1.8% higher grain yield and 19% higher stover yield) that flowered in 48 days.

*Milestone 5A.8.1.3: International Pearl Millet Training Course (2009) and Field Day (2006, 2008, 2010, 2012) conducted (KNR/CLLG/pearl millet team)*

ICRISAT hosted the 42<sup>nd</sup> All India Coordinated Pearl Millet Improvement Project (AICPMIP) annual meeting 14-16 May 2007. Approximately 130 delegates from all over India and 15 scientists from various disciplines in ICRISAT attended the meeting that reviewed the progress of research on pearl millet for the year 2006-07 and developed the plan for 2007/08. This was the first ever meeting of All India Coordinated Pearl Millet Project at ICRISAT. The projections of demand and supply of pearl millet for the year 2012 were discussed. It was felt by the group that the total production of pearl millet needed to be raised from the current 7-8 million tons to 11 million tons during the XI Plant period. Ten hybrids were identified for release in various agro-climatic zones that included MH 1328 (GHB 757) for the A1 zone (very dry parts of Rajasthan, Gujarat and Haryana receiving <400mm of rainfall); MH 1257 (B 2095), MH 1274 (NMH 68), MH 1272 (GHB 744), and MH 1299 (JKBH 676) for medium maturity; MH 1307 (GHB 732), MH 1302 (HHB 197), and MH 1295 (PHB 2168) for late maturity; for A zone (Rajasthan, Haryana, Gujarat, Delhi, Punjab, UP, and MP); MH 1257 (B 2095) and MLBH 134 for B zone (southern and central India); and MSH 167 (PB 727) for summer cultivation. At least eight of these are based on ICRISAT-bred male sterile lines. Several crop production-protection technologies were also finalized in the meeting.

*Milestone 5A.8.1.4: Technical information and public awareness documents developed and disseminated (KNR/CLLG/pearl millet team, annual)*

The *Pearl Millet Crop Management and Seed Production Manual*, co-authored by AICPMIP and three ICRISAT scientists (KN Rai, B Diwakar and R Bhattacharjee) was released during the 42<sup>nd</sup> All India Coordinated Pearl Millet Improvement Project (AICPMIP) annual meeting. The manual has been published under the ICAR-ICRISAT research partnership project. This comprehensive manual deals with pearl millet biology, its distribution and climatic requirements, and various aspects of crop management and seed production. Although it is written primarily in the context of agriculture in India, its contents have global application for students, teaching and training personnel, extension workers and farmers interested in development, crop management and seed production and marketing of pearl millet.

*Milestone 5A.8.1.5: Commercialization of pearl millet grains strengthened through researcher-farmer-industry alliances (KNR/CLLG/pearl millet team-annual)*

Previous on-farm research had shown that pearl millet hybrids substantially outyielded the long-standing pearl millet variety ICTP 8203 in Andhra Pradesh clusters. This research also showed that application of fertilizers further enhanced the grain yields. The extensive on-farm demonstrations in both Andhra Pradesh and Maharashtra village clusters were conducted. The field design and data collection procedures were streamlined and on-farm demonstrations were successfully conducted. Results are awaited.

### **III. Pigeonpea**

**Output Target 5A.1: About 15 high-yielding pigeonpea hybrids made available for cultivation in different environments (2006-2009)**

**Activity 5A.1.1: Development of widely adapted high-yielding hybrids for different environments**

*Milestone 5A.1.1.1: At least 100 new hybrid combinations evaluated to identify new fertility restorers/ male sterility maintainers (KBS/RKS, 2006-09)*

In order to identify new restorers and maintainers, 129 cross combinations were evaluated during 2006. A total of 118 new restorers and 11 new maintainers were found. These restorers and maintainers are in the process of further selection for restoration and sterility maintenance, respectively. The new B- and R- lines will be evaluated for characterization.

KB Saxena and RK Srivastava

*Milestone 5A.1.1.2: At least five high-yielding hybrids each in early- and medium-maturity duration identified for multilocation testing (KBS/RKS, 2007)*

In early maturity group, five high-yielding hybrids were identified. These hybrids exhibited grain yield superiority of 92 to 178% over the best control during 2006. The medium-maturity group is divided into Maruti (160 days) and Asha (180 days) maturity group. In the Maruti maturity group, five hybrids were short-listed for multi-location testing. The grain yield superiority of these hybrids over Maruti ranged between 44 and 63%. In the Asha maturity group, 11 hybrids were found promising with standard heterosis up to 62% over variety Asha. These hybrids will be tested across different locations during 2007.

KB Saxena and RK Srivastava

*Milestone 5A.1.1.3: At least 10 pigeonpea hybrids identified for on-farm testing (KBS/RKS, 2008)*

A total of 129 hybrids in extra-short, short and medium-durations were evaluated for yield and adaptability. Mean grain yield superiority of the extra short duration hybrids ranged from 7 to 158% over the check. In the short-maturity group, eight hybrids were found superior over the best check, with 23 to 121% grain yield superiority. In the medium-maturity group, 36 hybrids were found promising with grain yield superiority ranging between 10 and 152% over the popular check. About 10-15 outstanding hybrids will be evaluated in multilocation trials with NARS.

KB Saxena and RK Srivastava

*Milestone 5A.1.1.4: Elite pigeonpea hybrids evaluated for their resistance to major insects and diseases (HCS/SP/KBS/RKS, 2009)*

**Evaluation of hybrids and their parents for combined resistance to wilt and SM:** Two hundred and eighty eight short-duration and 358 medium-duration hybrids and their parents were evaluated for both wilt and SM resistance in wilt and SM sick plot following standard field evaluation techniques at ICRISAT-Patancheru.

Of the 280 short-duration hybrids and parents evaluated for both wilt and SM diseases, four hybrids (ICPH 3540, ICPH 3626, ICPH 3724, and ICPH 3725) and four lines (ICPL 88034, ICPL 20169-7, ICP 4865 and Uttaranchal 3) were asymptomatic for SM only. Four lines (ICP 11562, ICP 14646, ICP14857 and ICP 16169) were found asymptomatic to both wilt and SM diseases. Combined resistance to both diseases was not found in short-duration hybrid screened.

Among 358 medium-duration hybrids and parents, 42 were asymptomatic for both wilt and SM, 21 for wilt and 39 for SM. Combined resistance (<10%) to wilt and SM was found in 41 hybrids and their parents. Additionally 14 hybrids and their parents were resistant to wilt alone and 13 for SM alone.

SP Pande, KB Saxena and HC Sharma

#### **Relative susceptibility of maintainer and restorer lines to *Helicoverpa armigera***

Fifteen restorer and 13 maintainer lines along with resistant (ICPL 187-1 and ICPL 332) and susceptible (ICPL 87 and ICPL 87119) checks were evaluated for resistance to the pod borer, *H. armigera*. There were three replications in a randomized complete block design for each set. Data were recorded on visual damage rating for *H. armigera* (1 = <10% pods damaged and pods distributed all along the inflorescences, and 9 = >80% pods damaged, and pods poorly distributed along the inflorescences), recovery and overall resistance scores (1 = good, and 9 poor), and grain yield. Pod damage due to *H. armigera* was very high (damage rating 8-9) on all the test entries for the first flush. However, recovery resistance (number of pods produced, and pods damaged from second and third flushes) was better (score <5.3) in ICPB 2030, ICPB 2047, and ICPB 2048 compared to 6.0 of ICPL 332, 4.7 of ICPL 87119, and 9.0 of ICPL 87. Of these, ICPB 2030, ICPB 2047, and ICPL 87119 also had a better overall resistance score and grain yield than the susceptible check, ICPL 87.

Among the restorer lines, *H. armigera* damage rating scores varied from 7.3 on ICPL 187-1 to 9.0 on ICPL 87119. The lines ICPR 2324, ICPR 2336, ICPR 2897, ICPR 2899, ICPR 2904, ICPR 2913, ICPR 2920, and ICPR 2925 showed moderate recovery resistance scores (scores 4.7 to 5.7) following heavy pod borer damage in the first flush. Of these, grain yield was high (1528 to 2236 kg ha<sup>-1</sup>) in case of ICPR 2336, ICPR 2920, and ICPR 2925 as compared to ICPL 87119 (1256 kg ha<sup>-1</sup>) under unprotected conditions.

HC Sharma, KB Saxena and R Srivastava

**Output Target 5A.2: Genetically diverse pigeonpea hybrid parents (about 5-10 A-lines and 10-15 R-lines) with resistance to major biotic stresses developed (2009)**

### **Activity 5A.2.1: Development of high-yielding pigeonpea hybrid parents with resistance to major biotic stresses**

*Milestone 5A.2.1.1: At least six A<sub>4</sub> male-sterile and 15 fertility restorer lines with resistance to wilt and sterility mosaic disease developed (KBS/RKS/SP, 2007)*

*MTP Output Target 2007 5.1.2 PP: 6 A<sub>4</sub> male-sterile lines and 15 restorer lines with resistance to wilt and sterility mosaic disease developed*

Wilt and sterility mosaic (SM) are the two devastating diseases of pigeonpea in major pigeonpea growing areas worldwide. To address these bottlenecks, a specific resistance breeding program was taken up at ICRISAT. The original ICPA 2039 A<sub>4</sub> CMS line was susceptible to both wilt and sterility mosaic diseases. This line was crossed with germplasm lines resistant to wilt and/or sterility mosaic. The resulting F<sub>1</sub>s which maintained male sterility with resistance to wilt and/or sterility mosaic were selected. There were six wilt and sterility mosaic resistant male sterile lines, viz., ICPA 2086 (short duration, determinate), ICPA 2043, ICPA 2078 and ICPA 2101 (medium duration, Maruti maturity group, non-determinate), ICPA 2046 and ICPA 2048 (medium duration, Asha maturity group, non-determinate).

On similar lines, a restorer breeding program was initiated by crossing promising susceptible restorers with wilt and/or sterility mosaic resistant germplasm (R×R breeding). The segregating generations were evaluated in the wilt and sterility mosaic disease nursery at ICRISAT-Patancheru during 2006. There are 34 restorer lines with resistance to both wilt and sterility mosaic belonging to the medium maturity group. In the long-duration maturity group one restorer is found to have resistance to both wilt and sterility mosaic. All these wilt and sterility mosaic resistant A- and R- lines are being crossed. The F<sub>1</sub>s of these crosses are being evaluated for fertility restoration, grain yield and other important agronomic traits.

**Evaluation of CMS lines and their restorers for combined resistance to wilt and SM:** A total of 62 short-duration and 67 medium-duration maintainer lines and restorers were evaluated for both wilt and SM resistance in wilt and SM sick plot under artificial epiphytotic conditions following standard field evaluation techniques at ICRISAT-Patancheru. Chopped wilted pigeonpea plants were incorporated every year in the sick plot to maintain a threshold level of wilt fungus, *Fusarium udum*. For successful SM infection, every plant of the test entries was leaf inoculated with SM infested leaves using leaf staple technique at two-leaf stage. Susceptible cultivars ICP 2376 for wilt (resistant to SM) and ICP 8863 for SM (resistant to wilt) were planted along with test material, after every ten test rows as indicator rows. Data on the incidence of wilt and SM were recorded at seedling, flowering, pod initiation stage and at near maturity.

Of the 62 short-duration maintainers and restorers, four lines ICPBs 2086, 2101, 2078, and 2089-34 were found asymptomatic for both wilt and SM diseases. Additionally 14 lines (ICPAs 2041B, 2078, 2085, 2090, 2101, 2149, 2161, ICPBs 2040, 2085, 2089-24, 2089-29, 2089-35, 2149, 2164,) were asymptomatic to SM. Two lines (ICPA 2086 B, ICPA 2086 W) were resistant to wilt and SM (<10%).

Of the 67 medium-duration maintainers and restorers, five lines (ICPBs 2032, 2072, ICPHs 3423, 3442, and 3450) were asymptomatic to both wilt and SM and four lines (ICPAs 2049, 2070, ICPB 2048, Sriganesh B) were asymptomatic for SM alone. Further, 24 lines for both wilt and SM, one line (ICPA 2047) for wilt and eight lines (ICPAs 2040, 2091, ICPBs 2047, 2051, 2091, 2092, ICP 7035, Vaishali) had a resistant reaction for SM.

S Pande, KB Saxena and RK Srivastava

### **Output target 5A.3: Pigeonpea hybrid parents (25-30 A-lines and 50-55 R-lines) characterized for important agronomic traits and molecular diversity (2009)**

#### **Activity 5A.3.1: Assessing the agronomic and molecular diversity of pigeonpea hybrid parental lines**

*Milestone 5A.3.1.1: A/B- and R-lines characterized for important agronomic traits (KBS/RKS, 2008).*

A total of 41 B-lines were characterized during rainy season 2006 for important agronomic traits like seed color, 100-seed mass, days to flower, days to maturity, seeds pod<sup>-1</sup>, reaction to *Fusarium* wilt and sterility mosaic (SM) diseases, and grain yield. The observed variation among the B-lines for the above mentioned traits was significant. Variation for flowering ranged between 55 and 142 d, days to maturity between 90-192 d, plant



height 58–262 cm, seeds pod<sup>-1</sup> 3.4–5.6, and 100-seed mass 7–19.2 g. Out of 41 B-lines, 15 lines were determinate (DT) and 26 non-determinate (NDT) in growth habit.

During this season, 74 R-lines were also characterized for important agronomic traits. The variation observed was large for flowering (59 to 150 d), maturity (101 to 207 d), plant height (102 to 272 cm), seeds per pod<sup>-1</sup> (3.6–4.6) and 100-seed mass (6.4 and 12.9 g).

Eight R-lines of the A<sub>4</sub> system belonging to the early maturity group and 12 R-lines of the medium maturity group appeared good but were susceptible to wilt and/or sterility mosaic diseases. These lines were backcrossed during 2006 to incorporate resistance to wilt and/or sterility mosaic (SM) diseases.

KB Saxena and RK Srivastava

*Milestone 5A.3.1.2: Available male sterile (A/B) and fertility restorer (R) lines characterized using molecular markers (RKV/RKS/KBS, 2009).*

Activities were not initiated in 2007.

#### **Output Target 5A.4: Seed production technology for pigeonpea hybrids and their parents improved (2009)**

##### **Activity 5A.4.1: Developing an efficient seed production technology for pigeonpea hybrids and their parents**

*Milestone 5A.4.1.1: Improved seed production technology for pigeonpea hybrids and their parents developed (KBS/RKS, 2009)*

The observations recorded at Patancheru on out-crossing indicated that even 200 m isolation was not sufficient to maintain genetic purity of the material. Therefore, an isolation of 500 m may be useful for seed production. Studies were conducted to find out optimum row ratio of the parental lines for obtaining high seed yield. A row ratio of 4 A-lines: 1 B-line was found effective in producing seed of A-line at Patancheru during 2006/07. A row ratio of 4 A-lines: 1 R-line was also found suitable for hybrid seed production during the same year at Patancheru. Depending upon the planting date, latitude and altitude of the location, different seed rate and spacing would be needed to optimize yield. Therefore, partners were advised to multiply the seeds at a row ratio suitable for their locations. All the relevant details of seed production technology, agronomy, plant protection have been published in a seed production manual during 2006.

KB Saxena and RK Srivastava

#### **Output Target 5A5: Efficiency of hybrid pigeonpea breeding improved through strategic research (2010)**

##### **Activity 5A.5.1: Conduct strategic research to improve the efficiency of hybrid breeding**

*Milestone 5A.5.1.1: Cytology and genetics of A<sub>4</sub> CMS system and its fertility restorers investigated (KBS, 2007)*

*MTP Output Target 2007 5.1.1 PP: Cytology and genetics of the A<sub>4</sub> CMS system and its fertility restorers characterized*

Microsporogenesis and genetics of fertility restoration of A<sub>4</sub> cytoplasmic-nuclear male-sterility system in the pigeonpea was studied during the year 2006. The process of microsporogenesis in the male-sterile (ICPA 2039) and its maintainer (ICPB 2039) plants was normal up to the tetrad formation stage. The tapetal cells in the male-sterile anthers degenerated soon after tetrad formation, resulting in shriveled and degenerated microspores (Figures I-VIII). In the maintainer plants, the tapetal cells were normal and microspores were functional. The breakdown of tapetum before the completion of microsporogenesis was the major cause for the expression of male-sterility in A<sub>4</sub> CMS system.

Five crosses were attempted to study the genetics of fertility restoration for A<sub>4</sub> CMS system. All the F<sub>1</sub> plants in five crosses were fully fertile indicating the dominance of fertility restoring gene(s). The F<sub>2</sub> and BC<sub>1</sub>F<sub>1</sub> progenies of the crosses involving A<sub>4</sub> CMS line segregated for male-sterility and fertility. Among the five crosses studied, three (ICPA 2039 × ICP 12320, ICPA 2039 × ICP 11376, and ICPA 2039 × HPL 24-63) segregated in a ratio of 3 fertile : 1 sterile in F<sub>2</sub> generation whereas in the backcross generation a segregation of

1 fertile : 1 sterile was observed. This indicated the monogenic dominance nature of the fertility restoring gene. The pooled values over the three crosses also exhibited goodness of fit for 3 fertile : 1 sterile ( $\chi^2 = 0.11$ ) ratio in F<sub>2</sub> generation and 1 fertile : 1 sterile ( $\chi^2 = 1.06$ ) in backcross generation. The F<sub>2</sub> and backcross populations of cross ICPA 2039 × ICP 10650 segregated in the ratio of 15 fertile : 1 sterile ( $\chi^2 = 0.31$ ) and 3 fertile : 1 sterile ( $\chi^2 = 0.44$ ), respectively. This suggested the involvement of two dominant genes with duplicate gene action. The other cross (ICPA 2039 × ICP 13991) segregated in a ratio of 9 fertile : 7 sterile ( $\chi^2 = 2.10$ ) in F<sub>2</sub> generation and 1 fertile : 3 sterile ( $\chi^2 = 3.86$ ) in BC<sub>1</sub>F<sub>1</sub> generation indicating the presence of two complimentary genes for restoring the fertility of the male-sterile line.

*Milestone 5A.5.1.2: Genotype - environment interaction for the expression of male-sterility and fertility restoration assessed (KBS/RKS, 2009)*

The A<sub>4</sub> male-sterile lines ICPA 2039 and ICPA 2043, and hybrid combinations were evaluated at nine locations in India during rainy season 2006. Fertility restoration data were received from Jalna (Maharashtra), Coimbatore (Tamil Nadu), Manoharabad (Andhra Pradesh) and ICRISAT-Patancheru. Data on male sterility was not received from any location, except ICRISAT-Patancheru. Out of 32 hybrids evaluated, five hybrids (including ICPH 2671), were found to have 100% fertility restoration. In general, the fertility restoration was better at Coimbatore and Patancheru compared to Jalna and Manoharabad. This suggests that some genotype – environment interaction exists for the fertility restoration trait.

KB Saxena and RK Srivastava

*Milestone 5A.5.1.3: New sources of cytoplasm identified and diverse CMS systems developed (KBS/NM/RKS, 2010)*

In an attempt to diversify the cytoplasm sources further, a wild relative of pigeonpea *Cajanus lineatus* was chosen as donor for sterile cytoplasm. Three crosses *C. lineatus* × ICPL 99044, *C. lineatus* × ICPL 20176 and *C. lineatus* × ICPL 87119 were made at Patancheru during the year 2005. All these crosses were generation advanced in the field during rainy season, 2006. The cross involving *C. lineatus* × ICPL 99044 maintained sterility, while the F<sub>1</sub> of the crosses *C. lineatus* × ICPL 20176 and *C. lineatus* × ICPL 87119 were male fertile. BC<sub>3</sub>F<sub>1</sub> seeds were harvested from the cross *C. lineatus* × ICPL 99044.

KB Saxena, N Mallikarjuna and RK Srivastava

#### **Output target 5A.6: Trait-based breeding populations developed for selecting elite hybrid pigeonpea parental lines (2011)**

##### **Activity 5A.6.1: Development of trait specific (diverse maturity, disease resistance, seed and pod size) breeding populations for selecting new maintainers and restorers**

*Milestone 5A.6.1.1: For each trait, about 10-12 genetically diverse lines will be identified and crossed in a half-diallel mating scheme to generate B and R breeding populations for selection (RKS/KBS/SP, 2011)*

Three medium-maturity B-lines of genetically diverse origins were crossed with each other to generate six segregating populations for important agronomic traits. Similarly, genetically diverse R-lines were also selected to develop breeding populations. A set of 10 crosses in early × early maturity group and four crosses in early × medium maturity group were made during 2006. The F<sub>1</sub>s generated are being advanced and selections will be made for important agronomic traits.

RK Srivastava and KB Saxena

#### **Output Target 5A.7: Hybrid pigeonpea technology exchange, capacity building of partners and documentation (2010)**

##### **Activity 5A.7.1: Exchange improved technologies and new knowledge with ARIs, NARS, NGOs, private sector, and farmers' groups**

*Milestone 5A.7.1.1: ICRISAT partnerships with NARS and Hybrid Parents Research Consortium Partners strengthened (KBS/CLLG/SP, annual)*

Pigeonpea productivity has remained low at around 700 kg ha<sup>-1</sup> for the past four decades. To break this yield barrier ICRISAT and partners developed a stable cytoplasmic nuclear male sterility (CMS) system (Euphytica,

2005 145: 289-294) based hybrid pigeonpea technology with a potential of 30-40 % grain yield advantage in farmers' fields. Hybrid ICPH 2671 gave 60% grain yield advantage in 2005 and 2006. Simultaneously, its large scale seed production technology was also developed and evaluated at ICRISAT Patancheru. Subsequently, an interest group of seed companies and NARS was established and a training program was organized at ICRISAT on 25 May, 2007. One more training program was also conducted at Nanning, China. These awareness programs encouraged partner d organizations to promote hybrid pigeonpea technology.

Hybrid pigeonpea technology has created a clear niche for the involvement of the seed sector as there is an acute shortage of quality seed in pigeonpea. Since the hybrid technology is based on CMS, its seed production is relatively easy and thus permits easy adoption. ICPH 2671 is the first pigeonpea hybrid in the world with good yield advantage and seed sector sees potentially a high profitability from this venture and therefore they invested their resources in hybrid pigeonpea technology at the first available opportunity.

The demand for parental seeds of the hybrid was high in 2007 but ICRISAT could manage to provide 742 kg seed of A- & R-lines to 7 NARS and 15 private seed company partners to undertake 211 ha of hybrid seed production in diverse environments. From this endeavor more than 100 tons of hybrid seed of ICPH 2671 is expected. In 2008, this seed will be used by the seed companies for large-scale (on about 20 000ha) on-farm testing and test marketing of the hybrid.

The potential further impact of the adoption of this technology can also be seen by the fact that most of the seed companies have now also started their own research and development program using ICRISAT-bred new hybrid parental lines from which they will create their own hybrids. This will help in enhancing the productivity of pigeonpea.

ICRISAT's pigeonpea improvement group has further strengthened its partnership with NARS of various Asian and African countries. There are four joint projects with India, Nepal, Myanmar, Tanzania and Malawi. These projects aim at genetic improvement of pigeonpea for high yield, and resistance to diseases like wilt and sterility mosaic. The pigeonpea Hybrid Parents Research Consortium now had 18 Indian public and private sector seed companies as members. In addition there are four public sector organizations from China as part of the consortium. We conducted 2 training programs and field demonstrations on pigeonpea seed production technology. Scientists and technical staff of Myanmar, China and India were also provided short-term training. We supplied 2579 seed samples of improved pure lines/varieties/parental lines of hybrids of its research partners in India, Philippines, Myanmar, Nepal, South Africa, Kenya, Indonesia, USA, Australia and Zimbabwe.

*Milestone 5A.7.1.2: Seeds of elite parental lines, and hybrids multiplied and distributed to NARS and seed companies (KBS/RKS, annual)*

A total of 360 released lines, 58 advanced breeding lines, 66 hybrid trials (consisting of 652 entries), 39 hybrid nurseries (including 417 entries), 126 A-/B-line samples, 784 R-lines and 54 varieties were supplied by the pigeonpea breeding group, Patancheru, to various private sector, NGOs, and ARIs of ten countries, including India. A total of 2579 lines were supplied to these countries. Indian NARS and the private sector are major partners in pigeonpea research. Within India, a total of 339 released lines, 33 advanced breeding lines, 66 hybrid trials (consisting of 652 entries), 39 hybrid nurseries (including 417 entries), 126 A- and B-lines each, 784 R-lines and 54 varieties were supplied.

KB Saxena and RK Srivastava

*Milestone 5A.7.1.3: Technical information and public awareness literature developed and disseminated (KBS/HCS/SP, 2007)*

ICRISAT published an information bulletin on hybrid pigeonpea seed production and a pamphlet on hybrid pigeonpea entitled "Hybrid Pigeonpea – Seeds of Excellence" during the year 2006.

KB Saxena, HC Sharma and S Pande

*Milestone 5A.7.1.4: Capacity of NARS and seed sector scientists/technicians in hybrid breeding strengthened (KBS/CLLG, annual).*

There has been a constant interaction and feed back on technical information pertaining to pigeonpea seed production, agronomy, plant protection and post harvest management. During the year 2006, ICRISAT trained six scientists (one from PAU, Ludhiana; two from IARI; New Delhi and three from the private seed sector) in

hybrid pigeonpea technology. Besides, 25 technicians from private and public sectors were also trained on various aspects of hybrid pigeonpea breeding technology during the same period. A group of seed production officers from the Philippines visited ICRISAT for training in seed production technology during the same year.

KB Saxena and CLL Gowda

*Milestone 5A.7.1.5: Molecular markers and genetic maps developed and exchanged with the scientific community (RV/DAH/ RKS/HDU/NM/KBS, 2010).*

Activities were not initiated.

**Output 5B: Enhanced molecular genetic and phenotyping platforms for drought and salinity screening and parental lines of hybrid sorghum, pearl millet and pigeonpea with improved tolerance to abiotic stresses, made available to partners biennially (from 2008) with associated knowledge and capacity building in SAT Asia**

**Summary**

*Activities under this output are oriented towards largely molecular marker-based research to address drought and salinity tolerance both in sorghum and pearl millet; and reproductive-period heat tolerance and phosphorus (P) acquisition in pearl millet. Evaluation of QTL introgression lines for stay-green trait in sorghum showed that the effect of this trait on grain yield under drought stress results from their effect on grain number determined during the pre-flowering period rather than on grain size, which is determined during the post-flowering period. A standardized protocol to measure ABA in leaf tissues was developed. Evaluation of pearl millet lines tolerant or susceptible to drought showed high ABA levels in the tolerant lines, indicating their relationship with drought tolerance. A standardized protocol for screening for the P-acquisition ability from low-P sources was developed in pearl millet.*

**I. Sorghum**

**Output target 5B.1: At least five salinity-tolerant breeding lines/populations and a mapping population developed (2009)**

**Activity 5B.1.1: Developing/identifying salinity-tolerant improved breeding lines/populations and associated QTL**

*Milestone 5B.1.1.1: Five salinity-tolerant sorghum breeding lines/populations developed/identified (BVSR/VV, 2009)*

**Introgression of salinity-tolerance into high-yielding backgrounds:** A total of 84 F<sub>5</sub>s were derived from the crosses between salinity-tolerant breeding lines and high-yielding B-lines during the 2007 rainy season. Similarly, a total of 54 F<sub>5</sub>s were derived from the crosses between salinity-tolerant breeding lines and high-yielding R-lines during the 2007 rainy season. These are being further advanced during 2007 post-rainy season.  
BVS Reddy, A Ashok Kumar and Vincent Vadez

*Milestone 5B.1.1.2: New F<sub>6</sub> RIL mapping populations for salinity tolerance available for phenotyping and genotyping (CTH/BVSR/VV, 2009)*

Several crosses have been made to develop new RIL for QTL mapping of salinity tolerance. An important consideration to develop dual purpose sorghum is that tolerance for the production of grain appears to be different from the tolerance for the production of stover. For example, we found that sweet sorghum variety S35 was tolerant for the production of stover but not for the production of grain. Therefore, populations need to be developed specifically for each of these traits (stover or grain) as given below.

BTx 623 (tolerant) ICSR 93024-1 (sensitive) – (Grain)  
ICSV 93046 (tolerant) S 35 (sensitive) (Grain / Stover)  
BTx 623 (tolerant) S 35 (sensitive) (Grain / Stover)  
SP 39105 (tolerant) ICSR 93024-1 (sensitive) (Grain)

## II. Pearl millet

### **Output target 5B.1: At least five salinity-tolerant sorghum breeding lines/ populations of pearl millet identified and feasibility of breeding salinity tolerant hybrids assessed (VV/KNR/RB) (2009)**

#### **Activity 5B 1.1: Develop salinity-tolerant lines and populations in pearl millet and assess their hybrid potential under saline conditions**

*Milestone 5B.1.1.1: Inbred lines and populations identified as salinity-tolerant in preliminary evaluations re-evaluated for their salinity tolerance and yield potential (KNR/RB/VV, 2008)*

A trial of 34 entries consisting of 11 parental lines (4 male-sterile lines and 7 pollinators) and 28 hybrids derived from them, along with six salinity-tolerant populations and hybrids as checks, was conducted under non-saline condition at Patancheru during the 2007 rainy season to assess their yield potential. Among checks, the hybrid (ICMA 95333 × ICMP 451) based on salinity-tolerant male and female lines had the highest grain yield (3874 kg ha<sup>-1</sup>) and it flowered in 42 days, followed by another hybrid also based on salinity-tolerant parental lines (female parent ICMA 01222 and male parent ICMP 451) that had 3702 kg ha<sup>-1</sup> of grain yield and flowered in 42 days. In comparison, the dual-purpose commercial hybrid 7688 had 3803 kg ha<sup>-1</sup> of grain yield and flowered in 43 days. These two new hybrids, also had dry stover yield (4300 and 4000 kg ha<sup>-1</sup>, respectively) comparable to 7688 (3900 kg ha<sup>-1</sup>). Among the test hybrids, 10 of them produced 1.6–14.9% higher grain yield and 23 hybrids produced 4.6 to 70.8% higher dry stover yield in comparison to the check hybrid 7688. The days to flowering of the hybrids ranged from 40 to 50 days. A similar trial consisting of 13 entries (11 populations and 2 open pollinated varieties as checks) was conducted for salinity-tolerant populations during the rainy season. The grain and dry stover yield of popular dual-purpose check variety, ICTP 8203 was 3184 kg ha<sup>-1</sup> and 3200 kg ha<sup>-1</sup>, respectively, and it flowered in 40 days. Nine out of 11 populations produced 1.4–35.4% higher grain yield and 8 populations produced 18.5–118.7% higher dry stover yield in comparison to ICTP 8203. ICMS 7704 produced the highest grain and dry stover yield (4312 kg ha<sup>-1</sup> and 7100 kg ha<sup>-1</sup>, respectively) and flowered in 47 days.

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*Milestone 5B.1.1.2: Relationship between the salinity tolerance of hybrids and their parental lines assessed (KNR/RB/VV, 2010)*

Activity not initiated.

### **Output target 5B.2: Putative QTLs for salinity tolerance of grain and stover yield identified in sorghum and pearl millet (2009)**

#### **Activity 5B.2.1: Genotyping and phenotyping of mapping populations for salinity tolerance**

*Milestone 5B.2.1.1: Putative QTLs for salinity tolerance based on 160 RILs from one mapping population identified (CTH/SS/VV, 2010)*

A first round of phenotyping of 160 RILs from the cross between 841B (tolerant) × 863B (sensitive) was performed early in 2007, which revealed a large range of variation for seed yield under saline conditions, ranging from close to zero, up to about 8 g plant<sup>-1</sup>. The salt stress imposed in that experiment was relatively severe since the mean seed yield under salinity stress (2.34 g kg<sup>-1</sup> soil, equivalent to the application of a 200 mM NaCl solution at a rate of 200 mL kg<sup>-1</sup> soil), was only 11% of the seed yield under controlled conditions. By contrast, the effect of salt stress on the stover yield was relatively more moderate, though still fairly severe as the mean stover yield under saline conditions reached 33% of that under control conditions.

In that experiment, the parents confirmed once again their large contrast. Tolerant parent 841B had a seed yield of 3.78 g plant<sup>-1</sup> whereas sensitive 863B had a yield of 1.44 g plant<sup>-1</sup> only. There was no difference between these parental lines for stover weight under saline conditions, indicating that, as in the case of sorghum, the mapping of QTL for stover production under saline conditions in pearl millet has to be done with specific populations, with parents contrasting specifically for each of grain and stover.

In addition, we tested 20 pearl millet inbred lines along with 4 inbred testers, and the resulting 80 testcross hybrids under both saline and controlled conditions. A first trial was done during the 2006-07 post-rainy season and gave mixed results, in particular for the inbreds that showed a high degree of mortality, mostly due to overwatering and then waterlogging under salt stress. In a repeat experiment in early 2007, the inbreds were kept separated from the hybrids to adapt the watering regime to the growth rate of each set of materials. The purpose of this experiment was to identify a suitable tester with good combining ability so that the RIL population above could be screened under salinity in forms of testcross hybrids. From this, it appears that the specific combining ability of ICMA 90111 and ICMA 92666 would be suitable to test the testcross RILs using these testers.

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**Physiological mechanism of salinity tolerance:** Physiological experiments are in progress to understand the mechanisms involved in the differences in salinity tolerance between these parental lines. In short, we tested the response of pearl millet inbreds to salt application at the time of flowering. Plants were grown until that stage in pots or in hydroponic conditions. The salt application in soil was equivalent to the one used in our screening (2,34 g NaCl kg<sup>-1</sup> soil), and in hydroponic it was 150 mM. Both in hydroponics and soil, the salt dose was applied in three split doses over 3 consecutive days. We had two goals: (i) to measure the response of transpiration to a salt application, the hypothesis being that salt induces a closure of stomata, which depresses the overall photosynthesis, and this might be part of the effect of salt; (ii) to measure the apparent Na concentration in the xylem to detect putative differences between the lines. It appears that these two parameters vary when plants are treated with salt: (i) the transpiration drop following salt treatment appears to be more severe in the case of 841B than in the case of 863B under soil conditions but the results are contrary under hydroponic conditions; (ii) salt concentration in the xylem (total Na accumulated during the course of the experiment divided by total transpiration during that time) was about twice as high in sensitive 863B. These data may indicate differences between the two genotypes in how Na gets loaded in the xylem, with some putative differences in the root hydraulics.

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*Milestone 5B.2.1.2: Putative QTLs for salinity tolerance based on 35 BC<sub>6</sub>F<sub>3</sub> contiguous segment introgression lines identified (CTH/SS/VV, 2010)*

No report yet

*Milestone 5B.2.1.3: New F<sub>6</sub> RIL mapping populations for salinity tolerance available in pearl millet for phenotyping and genotyping (CTH/BVSR/KNR/VV, 2009)*

No report yet

**Output target 5B.3: Breeding value of putative terminal drought tolerance QTLs in pearl millet documented (2009)**

**Activity 5B.3.1: Publication of earlier results on drought tolerance QTL and gene pyramiding**

*Milestone 5B.3.1.1: Publication of results from marker-assisted selection for the linkage group 2 drought tolerance QTL into the genetic background of two parental lines (CTH/FRB, 2008)*

No report yet

**Output target 5B.4: Pearl millet germplasm with superior P-acquisition identified (2009)**

**Activity 5B.4.1: Development of an effective protocol and identification of germplasm with enhanced P-acquisition ability**

*Milestone 5B.4.1.1: An effective P-acquisition protocol applicable for large-scale screening developed (VV/HDU, 2007)*

*MTP Output Target 2007 5.2.1 SOPM: Protocol for consistent and reliable P-acquisition data applicable to large numbers of entries developed for proto-drought tolerance screening in pearl millet*

A protocol has been developed based on the trials and analysis done in the past few years with regards to screening of tolerance to low soil P conditions in pearl millet. This protocol has been developed based on the fact that pearl millet seeds are small and that plant establishment is a key factor to a successful performance under low P conditions. To get uniform sowing depth, a template making holes of a standard depth is used, in which seeds are placed. Several seeds were usually sown per hill, and then thinned to one seedling per hill. It was observed that thinning was affecting the development of the remaining seedling (probably by disturbing roots of the remaining seedling). Therefore, 9 seeds are now planted per pot, one each into an individual hole made with the template, and most uniform 3 seedlings are retained. The protocol is also based on an observation that growing 3 plants per replicate pot helps in decreasing the replicate-to-replicate variation. We are also aware of a genotype  $\times$  nitrogen interaction effect under low P soil, which has to be taken into account at the time of screening for low-P tolerance (choice has to be made and repeat experiment should use the same N source). Finally, we have found that a small difference in soil Olsen P value could bring about large differences in the response of pearl millet plants. Therefore, the same soil lot is used for each experiment, and this lot is first homogenized with a concrete mixer prior to preparing the soil:sand mix (1:1 v/v).

This protocol is now routinely used to screen genotypes for their tolerance to low soil P conditions. A set of experiments has been performed using 20 pearl millet inbred parents and appears to be working well (little experimental error), even with small seeded inbred lines from the F<sub>6</sub> generation. This protocol has also been tested with testcross hybrids made from these 20 inbred parents onto 4 different testers. We obtained very good data with the new protocol (mixing of soil batch with concrete mixture, uniform sowing depth with template, 3 plants per pots), and cv under low P around 15% only. In this experiment, we found a strong relation ( $r^2 = 0.55$  in RP1, and  $r^2 = 0.36$  in RP2) between the biomass yield under low P and the biomass yield under control conditions (no P limitation), which indicates that plant vigor explains part of the performance under low P. Therefore, the regression equation was used to calculate an estimated biomass yield,  $\hat{Y}_s$ , under low P, from which residuals were calculated as  $Y_s - \hat{Y}_s$ . These residuals would then account for low P tolerance per se. Previous screening had shown some genotypic contrast between LGD 1-B-1-10 (low biomass under low P) and ICMP 85410 - P7 (high biomass under low P), and between 81B - P6 (low biomass under low P) and ICMP 451 - P8 (high biomass under low P). We found similar differences here based on biomass. However, the residuals (after removing the component of the variation that account for growth potential) were lower for ICMP 85410 - P7 than for LGD 1-B-1-10, and the residual for ICMP 451 - P8 was only slightly higher than 81B - P6. These data indicated that the range of variation for low P tolerance between these two pairs of inbred parents was unsuitable for QTL mapping of low P tolerance. By contrast we found a good contrast in the residuals between inbred ICMP 451 - P6 (tolerant) and H 77/833-2-P5 (NT) (sensitive), and between PRLT 2/89-33-Bulk (tolerant) and H 77/833-2-Bulk (sensitive).

The current orientation in these screenings would be to enlarge the range of variation available in the parental lines of existing populations for tolerance to low P soil. We also used that protocol to investigate the effect of either the application of 1000  $\mu$ L of a 32 mM KH<sub>2</sub>PO<sub>4</sub> solution (equivalent to about 10 times the amount of P in a pearl millet seed), or a seed coating at different rates (with a target of about 10 times the amount of P per seed, equivalent to about 0.01 mg P. The seed coating application would correspond to 170 g of granular KH<sub>2</sub>PO<sub>4</sub> per kilogram of seeds. The response of plant growth to these applications appears to be very promising and these data are summarized in a paper draft that will be submitted for publication.

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*Milestone 5B.4.1.2: Pearl millet germplasm with superior P-acquisition from low-P sources identified (VV, 2009)*

Activities were not undertaken.

**Output target 5B.5: At least five pearl millet breeding lines with tolerance to high air temperatures (>45°C) during reproductive stage developed (2009)**

**Activity 5B.5.1: Evaluate a diverse range of parental lines, advanced breeding lines and populations for high temperature tolerance during flowering and grain-filling period; and identify major QTL associated with this trait**

*Milestone 5B.5.1.1: Breeding lines with >70% seedset under field conditions at high temperatures identified/developed and their tolerance under greenhouse conditions validated (KNR/RB/VV, 2009)*

Most of the hybrids bred for rainy-season adaptation have been found to become male-sterile, or set very poor seed during the summer season if flowering takes place at a time when the air temperatures could be as high as 46–48 °C. Few of the hybrids, however, set excellent seeds, indicating genetic variability for thermo-tolerance during the reproductive stage. With the assistance of MAHYCO and Nitya Seeds, 104 progenies from 10 B-lines and one R-line were evaluated for seedset under open pollination in a summer planting at Jodhpur and Sanchor (Rajasthan, India) and under greenhouse conditions at ICRISAT-Patancheru with 842B as check. The field trial at Jodhpur and Sanchor failed as the peak temperature during flowering time did not exceed 42°C. Under greenhouse conditions at ICRISAT-Patancheru, all the 12 lines had good seedset (56–92%) at air temperature ranging from 45–47 °C during stigma emergence. However, the relative humidity in the greenhouse was high and hence the field situation encountered during the hot summer could not be simulated. It appears that greenhouse screening facilities with dry and high temperature environment (above 45°C) will need to be created and used to effectively screen for this trait.

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*Milestone 5B.5.1.2: Relationship between hybrids and their parental lines for tolerance to high temperatures during reproductive stage quantified (KNR/RB/VV, 2010)*

*Milestone 5B.5.1.3: QTL for high temperature tolerance from two diverse mapping populations identified (KNR/RB/VV, 2012)*

Lines with consistent performance for high temperature tolerance are yet to be identified before initiating the mapping population development and QTL identification.

#### **Output target 5B.6: Protocol for consistent and reliable estimation of abscisic acid (ABA) content of drought-stressed tissues developed as an aide to drought tolerance screening in pearl millet**

##### **Activity 5B.6.1: A protocol developed to measure ABA in leaf tissue (2007)**

*MTP Output Target 2007 5.2.2 SOPM: Protocol for consistent and reliable estimation of ABA content of drought-stressed tissues developed as an aide to drought tolerance screening in pearl millet*

This protocol was developed with the help of the mycotoxin laboratory and used an ELISA technique. The preliminary evaluations were done on groundnut leaves and later adapted to pearl millet leaves. Free ABA was estimated in the first fully developed leaves of every plant. ABA was assayed by competitive enzyme-linked immuno-sorbent assay (ELISA) according to the method of Tuberosa et al. (1982?) with minor modifications. Polyclonal antibodies were raised against antigen - ( $\pm$ ) cis-trans ABA (*Sigma Aldrich*) previously conjugated through its C<sub>1</sub> carboxyl site to a carrier protein bovine serum albumin (BSA) adopting the method of Weiler (1984). Presence of antibodies to the hapten ABA was checked by standard methods. Cross reaction of polyclonal antibodies with BSA to avoid their non-specific reaction was carried out before its use for ELISA. After coating ELISA plates with antigen, plates were loaded with 1% milk to minimize non-specific binding. The antigen coating dilution, antibodies and alkaline phosphatase-linked secondary antibodies dilutions were chosen, so that under assay conditions, absorbance  $A_{405} = 1.0$  for blank was obtained after approximately 1h incubation with p-NPP substrate. Several spiking experiments to detect recovery of known ABA concentration were conducted to validate this technique. For sample extraction and further removal of bio-chemically inert ABA conjugates, we used the ethyl acetate fractionation technique according to Ryu and Li (1994).

ABA was first measured in a set of 4 groundnut genotypes that were grown in PVC tubes. The size of these cylinders mimic fairly closely the volume of soil that a peanut plant would have in a field at current sowing density. Plants were grown for 30 days. Fifteen plants per genotype were grown. At 30 DAS, 5 plants per genotype were harvested to assess root depth and root dry weight in the different 15-cm layers. The other 10 cylinders were saturated with water, and 5 plants maintained under well-watered conditions (WW) and the other 5 left with no further irrigation (water stressed, WS). Cylinder weight was recorded on a regular basis, usually every 3 days, providing data on the volumes of water uptake and the related kinetics. We found that 2 genotypes had a “conservative behavior”, with their water uptake decreasing quickly after suppressing irrigation, although these two genotypes (TAG24 and ICGV86031) were able to take up water for about 40 days after stress exposition. Two other genotypes had an “opportunistic behavior” and changed little their pattern of water uptake after stress imposition compared to WW plants, but ran short of water sooner than the other two genotypes. It



was then interesting to notice that the first two genotypes had higher ABA levels, whereas the two others had lower ABA levels.

ABA concentration in four genotypes differing in the response of their water uptake to water stress exposure.

The ABA measurement has also been used to compare PRLT/89-33 and H77/833-2 under well-watered conditions. We found that PRLT/89-33 had higher ABA levels, both during pre-flowering and post-flowering stages. Such differences appeared to be related to a lower rate of water loss per unit of leaf area in PRLT/89-33 compared to H77/833-2. This mechanism would allow PRLT/89-33 to save water from the soil profile when water is available, making it available later on to support grain filling when moisture is limiting.

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### **Output 5C: Germplasm and improved breeding lines with high and stable grain Fe and Zn density in sorghum and pearl millet made available to specific partners biennially (from 2008) with associated knowledge and capacity building**

#### **Summary**

*Activities under this output address grain quality and safety issues that, among other factors, impact on nutritional security. Genetic enhancement of grain iron (Fe) and zinc (Zn) in sorghum and pearl millet, and assessment of mycotoxins in the harvested and stored grain is the focus of specific research activities. Thus, in a trial of 164 sorghum B-lines, Fe content varied from 22 to 49 ppm and Zn content varied from 15 to 37 ppm. In pearl millet, 93 restorer lines showed a much wider range, with 28–101 ppm Fe and 27–67 ppm Zn. Since pearl millet populations are highly heterozygous and heterogeneous, they contain substantial variability. Analysis of S<sub>1</sub> progenies from four improved pearl millet populations showed them having 36–120 ppm Fe and 30–89 ppm Zn. An efficacy test of recurrent selection for grain Fe and Zn in two populations showed that one cycle of recurrent selection could change Fe content by 11–12% and Zn content by more than 7%. Forty-seven cultures of fusarium species from molded sorghum grains from Patancheru showed it consisting of six species with Fe. proliferatum producing high levels of FB1 and FB2 fumonisins. Grain samples collected from farmers fields at harvest and from storage showed a wider range of aflatoxin contamination (0–362 g/kg) and fumonisin concentration (0–254 g/kg) in sorghum than in pearl millet samples (0–32 g/kg aflatoxin and 0–26 g/kg fumonisin).*

#### **I. Sorghum**

**Output target 5C.1: Sorghum germplasm lines/breeding lines with stable and high grain Fe (40–50 ppm) and Zn (30–40 ppm) contents identified and their character association, and inheritance studied (2009)**

**Activity 5C.1.1: Screening of germplasm and breeding lines for grain Fe and Zn and evaluating for grain yield and agronomic traits**

*Milestone 5C.1.1.1: Five each of germplasm lines/breeding lines with stable and high grain Fe (40–50 ppm) and Zn (30–40 ppm) contents identified (BVS/HDU, 2008)*

*MTP Output Target 2007 5.3.1: Correlations of high grain Fe (40-50 ppm) and Zn (30-40 ppm) contents with grain yield and agronomic traits estimated for sorghum hybrid parents*

**Core collection evaluation for micronutrient density:** All the 2974 sorghum core germplasm accessions were planted during the 2005 postrainy season, 1401 accessions were assessed for their grain Fe and Zn contents and 153 accessions were selected. The remaining accessions (1062 accessions barring 511 which are highly photoperiod-sensitive) whose grain Fe and Zn contents could not be estimated were planted during the 2006–07 postrainy season to assess the genetic variability. For the sake of convenience, the accessions were evaluated (in contiguous blocks) in three separate groups classified based on days to 50% flowering (early: ≤65 days; medium: 66 to 80 days; late: >80 days). The early group consisted of 322 accessions apart from 4 checks repeated 8 times; the medium group consisted of 460 accessions along with the 4 checks repeated 12 times; the late group consisted of 280 accessions along with 4 checks repeated 7 times. Data were collected on days to 50% flowering, plant height, grain yield, 100-grain weight, grain color, plant agronomic aspect, panicle shape, panicle compactness, glume color, glume coverage, presence/absence of seed sub-coat. The grain samples

harvested from selfed panicles of all these accessions and those harvested from open-pollinated panicles wherever sufficient quantities available were processed for estimation of grain Fe and Zn contents. The results are awaited.

**Evaluation of established hybrid parents for grain Fe, Zn and Al contents:** Identification of hybrid parents with high grain Fe and Zn contents enable faster development of hybrids with high these contents and thereby quicker dissemination to the end users. Over the years the sorghum program at ICRISAT developed 758 A-/B-lines and 922 R-lines for various traits. During the 2006 post-rainy season seed samples from the 2 replications of 691 hybrid parents (288 B-lines and 403 R-lines) were processed and sent for lab analysis. Data on grain Fe and Zn contents of 164 B-lines was obtained. Results on grain Al content are awaited. From among the 164 B-lines the grain Fe content ranged from 22.4 ppm to 49.2 ppm and the grain Zn content ranged from 15.1 ppm to 37.1 ppm.

**Breeding sorghum for high grain Fe and Zn contents:** In order to identify the transgressive segregants and study the maternal effects for grain Fe and Zn contents, crosses were made between adapted breeding lines and unadapted germplasm lines (contrasting for Fe and Zn contents) in three diallels (diallel set 1: 26 lines contrasting for grain Fe content, set 2: 25 lines contrasting for grain Zn content and set 3: 31 lines contrasting for both grain Fe and Zn contents) in the 2006-07 post-rainy season. A total of 223 F<sub>1</sub>s made (75 in diallel set 1, 75 in diallel set 2 and 73 in diallel set 3) will be advanced during the 2007 post-rainy season.

**Introgressing grain micronutrients (Fe and Zn)-dense germplasm lines into high yielding breeding lines with elite agronomic backgrounds:** For grain micronutrient dense B-line development, 29 F<sub>4</sub>s were selected from 23 F<sub>3</sub>s and 62 F<sub>5</sub>s from 75 F<sub>4</sub>s were selected during the 2007 rainy season and for grain micronutrient dense R-line development, 32 F<sub>5</sub>s were selected from 54 F<sub>4</sub>s during the 2007 rainy season. These are being further advanced with selection during the 2007 post-rainy season.

BVS Reddy, A Ashok Kumar and HD Upadhyaya

*Milestone 5C.1.1.2: Correlations of grain Fe and Zn contents with grain yield and size and agronomic traits estimated (BVSR, 2008)*

From a set of 40 diverse sorghum lines involving parental lines of popular hybrids, varieties, yellow endosperm lines and germplasm lines evaluated during the 2004-05 post-rainy season, 22 entries were selected (either Fe >40 ppm or Zn >25 ppm) and further evaluated in a trial along with the check 296B in the 2006-07 post-rainy season. From a total of 1401 accessions (core germplasm set 1) evaluated for their grain Fe and Zn contents, 153 accessions with grain Fe content >45 ppm and grain Zn content >35 ppm were selected. Based on grain threshability and ease of processing, the selected entries were evaluated in two separate trials, a non-threshable line trial consisting of 45 entries with 100% glume coverage and resembling the race *bicolor*, and a freely threshable lines trial consisting of the remaining 108 germplasm accessions along with six checks in the 2006-07 post-rainy season. The grain samples were processed for estimation of grain Fe, Zn and Al contents.

A total of 86 entries consisting of a diverse range of breeding material were evaluated in a triplicated trial during post-rainy season 2003-04 to identify lines with high grain Fe, Zn and  $\beta$ -carotene contents. Forty lines with high and low content were selected and evaluated for agronomic traits and stability of grain Fe, Zn and  $\beta$ -carotene contents during the 2004-05 post-rainy season. The correlations based on the two-year data are given in Table 1.

Grain yield and grain-Fe and Zn contents are negatively correlated, but Grain-Fe and  $\beta$ -Zn contents are positively (and highly) correlated.

**Table 1. Estimates of correlation coefficients in sorghum breeding and germplasm lines for agronomic and grain traits (2003-04 and 2004-05)**

|                                   | <i>Days to 50% flowering</i> | <i>Plant height (m)</i> | <i>Grain yield (t ha<sup>-1</sup>)</i> | <i>Grain size (g 100<sup>-1</sup>)</i> | <i>Grain Fe (ppm)</i> | <i>Grain Zn (ppm)</i> |
|-----------------------------------|------------------------------|-------------------------|----------------------------------------|----------------------------------------|-----------------------|-----------------------|
| Plant height (m)                  | 0.33                         | 1                       |                                        |                                        |                       |                       |
| Grain yield (t ha <sup>-1</sup> ) | -0.46**                      | -0.03                   | 1                                      |                                        |                       |                       |

|                                  |       |       |         |       |        |   |
|----------------------------------|-------|-------|---------|-------|--------|---|
| Seed size (g 100 <sup>-1</sup> ) | -0.10 | 0.28  | 0.16    | 1     |        |   |
| Fe (ppm)                         | 0.29  | -0.05 | -0.48** | -0.31 | 1      |   |
| Zn (ppm)                         | 0.37* | 0.42* | -0.63** | -0.23 | 0.66** | 1 |

\*, \*\* means Significant at 5% level and Significant at 1% level respectively.

**Core collection evaluation for micronutrient density:** The core collection along with four controls (known for their Fe and Zn contents) were evaluated in augmented design at ICRISAT-Patancheru in the 2005 post-rainy season. The accessions were evaluated (in contiguous blocks) as three separate groups classified based on days to 50% flowering (early: ≤ 65 days; medium: 66 to 80 days; late: > 80 days). The early group comprising 1095 accessions; the medium group comprising 1128 accessions; and the late group comprising of 751 accessions. The grain samples harvested from selfed panicles of 702 accessions of early maturity, 461 accessions of medium maturity, and 238 accessions of late maturity (making a total of 1401 accessions) were sent for grain Fe and Zn content estimation. In the core collection also, grain yield and grain-Fe and Zn contents are negatively correlated (though significant; but low in magnitude), but grain-Fe and -Zn contents are positively correlated (Table 2) like in the previous set.

**Table 2. Estimates of correlation coefficients in sorghum germplasm lines for agronomic and grain traits (2005-06)**

|                                   | <i>Days to 50% flowering</i> | <i>Plant height (m)</i> | <i>Grain yield (t ha<sup>-1</sup>)</i> | <i>Grain size (g 100<sup>-1</sup>)</i> | <i>Grain Fe (ppm)</i> | <i>Grain Zn (ppm)</i> |
|-----------------------------------|------------------------------|-------------------------|----------------------------------------|----------------------------------------|-----------------------|-----------------------|
| Plant height (m)                  | 0.54**                       | 1                       |                                        |                                        |                       |                       |
| Grain yield (t ha <sup>-1</sup> ) | -0.02                        | -0.09**                 | 1                                      |                                        |                       |                       |
| Seed size (g 100 <sup>-1</sup> )  | -0.31**                      | -0.15**                 | 0.08**                                 | 1                                      |                       |                       |
| Fe (ppm)                          | 0.07*                        | 0.22**                  | -0.16**                                | -0.12**                                | 1                     |                       |
| Zn (ppm)                          | 0.20**                       | 0.38**                  | -0.21**                                | -0.15**                                | 0.61**                | 1                     |

n-2= 1393

\*, \*\* means Significant at 5% level and Significant at 1% level respectively.

The remaining 1062 accessions (barring 511 which are highly photoperiod-sensitive) whose grain Fe and Zn contents could not be estimated were planted during the 2006-07 post-rainy season to assess the genetic variability. For the sake of convenience, the accessions were evaluated (in contiguous blocks) in three separate groups classified based on days to 50% flowering (early: ≤ 65 days; medium: 66 to 80 days; late: > 80 days). Correlations for the early and medium groups are given in Table 3.

Unlike the previous sets, grain yield and grain-Fe and Zn contents are not highly correlated. However, grain-Fe and Zn contents are positively correlated in core germplasm lines (Table 3) as in the previous sets.

**Table 3. Estimates of correlation coefficients in sorghum germplasm lines for agronomic and grain traits (2005-06)**

|                                   | <i>Days to 50% flowering</i> | <i>Plant height (m)</i> | <i>Grain yield (t ha<sup>-1</sup>)</i> | <i>Grain (g 100<sup>-1</sup>)</i> | <i>Grain Fe (ppm)</i> | <i>Grain Zn (ppm)</i> |
|-----------------------------------|------------------------------|-------------------------|----------------------------------------|-----------------------------------|-----------------------|-----------------------|
| Plant height (m)                  | 0.50**                       | 1                       |                                        |                                   |                       |                       |
| Grain yield (t ha <sup>-1</sup> ) | -0.02                        | 0.002                   | 1                                      |                                   |                       |                       |
| Seed size (g 100 <sup>-1</sup> )  | -0.57**                      | -0.65**                 | 0.07*                                  | 1                                 |                       |                       |
| Fe (ppm)                          | 0.36**                       | 0.46**                  | -0.06*                                 | -0.64**                           | 1                     |                       |
| Zn (ppm)                          | -0.03                        | 0.09**                  | -0.06*                                 | 0.06*                             | 0.39**                | 1                     |

n-2= 853

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\*, \*\* means Significant at 5% level and Significant at 1% level respectively.

BVS Reddy and A Ashok Kumar

*Milestone 5C.1.1.3: G E interactions for grain Fe and Zn contents assessed (BVSR/HDU, 2008)*

With a view to assess the effect of micronutrient fertilizer application on sorghum grain micronutrient contents, 12 sorghum lines (including hybrid seed parents, restorer lines and popular varieties) contrasting for grain Fe and Zn (high and low) contents were grown in vertisols (medium black soil) and alfisols (red sandy loam soils) with a combination of five different levels of micronutrients in the 2005 rainy season. The five treatments included (T<sub>1</sub>): recommended NPK + zero micronutrients; second level (T<sub>2</sub>): recommended NPK + recommended Fe @ 10 kg ha<sup>-1</sup>; (T<sub>3</sub>): recommended NPK + recommended Fe @ 10 kg ha<sup>-1</sup> + recommended S @ 30 kg ha<sup>-1</sup> + recommended B @ 0.5 kg ha<sup>-1</sup>; fourth level (T<sub>4</sub>): recommended NPK + Zn @ 10 kg ha<sup>-1</sup> + recommended S @ 30 kg ha<sup>-1</sup> + recommended B @ 0.5 kg ha<sup>-1</sup>; and fifth level (T<sub>5</sub>): recommended NPK + Zn @ 10 kg ha<sup>-1</sup>. The same experiment is being repeated during the 2007 postrainy season for confirmation of results.

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**Output 2C: Output target 2012.5.3.1 SOPM.: Effectiveness of recurrent selection for grain from Fe and Zn and its effect on grain yield and agronomic traits in pearl millet demonstrated**

*2007 Milestone: Information on genetic gains from one cycle of recurrent selection for grain Fe and Zn, and its effect on grain yield and agronomic traits in two open-pollinated varieties (AIMP 92901 and GB 8735).*

*2008 Milestone: Effectiveness of one cycle of recurrent selection for grain Fe and Zn in AICMP 92901 and GB 8735 documented.*

*2009 Milestone: Information on genetic gains from one cycle of recurrent selection for grain Fe and Zn and its effect on grain yield and in agronomic traits in two additional populations (CGP and GGP) generated.*

*2010 Milestone: Effectiveness of one cycle of recurrent selection for grain Fe and Zn content in CGP and GGP documented.*

*2011 Milestone: Information on genetic gains from second cycle of recurrent selection for grain Fe and Zn, and its effect on grain yield and agronomic traits in a commercial variety (ICTP 8203) generated.*

*2012 Milestone: Effectiveness of two cycles of recurrent selection for grain Fe and Zn contents in ICTP 8203 documented.*

Considering the high heritability of grain Fe and Zn, highly significant positive correlation between Fe and Zn, and indications of either positive or no correlation of Fe and Zn with grain size, recurrent selection for grain Fe and Zn without any adverse effect on grain yield is likely to be fairly effective in pearl millet. This hypothesis is being tested on five populations that have been identified as having high levels of grain Fe and Zn contents.

Nine progenies with high grain Fe and Zn content were selected separately from both AIMP 92901 (81.5–104.0 mg kg<sup>-1</sup> Fe and 57.0–68.0 mg kg<sup>-1</sup> Zn) and GB 8735 (78.5–104.5 mg kg<sup>-1</sup> Fe and 57.0–59.5 mg kg<sup>-1</sup> Zn), and random mated (half diallel) in the 2006 postrainy season to initiate recurrent selection. The C<sub>1</sub> cycle bulks produced from progenies selected for high iron content—C<sub>1</sub> (Fe), and the one produced from progenies selected for high zinc content—C<sub>1</sub> (Zn), and original bulks (C<sub>0</sub>) of both the populations were evaluated in four replications during the 2006 rainy and 2007 postrainy seasons. The grain samples produced from both the seasons were analyzed at ICRISAT, laboratory to estimate Fe and Zn content. The differences among the population bulks and their interaction with the environments were highly significant (P < 0.01) both for grain Fe and Zn contents.

Based on mean performance across the two environments, C<sub>1</sub> (Fe) bulks had 21–22% higher grain Fe content than the C<sub>0</sub> bulks of both AIMP 92901 (66 ppm) and GB 8735 (62 ppm). Larger genetic gains with 39–40% higher Fe was observed in C<sub>1</sub> (Fe) bulks than in the C<sub>0</sub> bulks of AIMP 92901 and GB 8735 in the 2007 postrainy season with a trial mean of 54.4 ppm for AIMP 92901 and 50.3 ppm for GB 8735, than in the 2006 rainy season that although it had a higher trial mean (84.5 ppm for AIMP 92901 and 79.6 ppm for GB 8735) showed

genetic gain of only 11–12%. Further, the C<sub>1</sub> (Zn) bulk of AIMP 92901 had 73 ppm Fe (10% higher than C<sub>0</sub> bulk) and this difference was statistically significant. However, there was no significant difference between the C<sub>1</sub> (Zn) and C<sub>0</sub> bulk for Fe in GB 8735. Largest genetic gains in C<sub>1</sub> (Zn) bulk for Fe (27% in AIMP 92901 and 23% in GB 8735) were observed in the 2007 post-rainy season and practically no gain was observed in the 2006 rainy season. Based on the mean performance across these two environments, comparison of C<sub>1</sub> (Zn) and C<sub>1</sub> (Fe) bulks with C<sub>0</sub> bulks showed that selection for Fe was at least as (or even more) effective than direct selection for Zn content. For instance, C<sub>1</sub> (Fe) bulks had 12% more Zn than C<sub>0</sub> bulk in AIMP 92901 (50 ppm) and 18% more in GB 8735 (45 ppm), while the C<sub>1</sub> (Zn) bulk had 7% more Zn than C<sub>0</sub> bulk in AIMP 92901 and 15% more Zn in GB 8735. The genetic gains detected for Zn were more consistent across the environments for the C<sub>1</sub> (Zn) bulk, with 7% more Zn than the C<sub>0</sub> bulk of AIMP 92901 and 12–18% more Zn for GB 8735. The C<sub>1</sub>(Fe) bulks had large variation in its Zn content across the environments, with 7% less to 35% more Zn as compared to C<sub>0</sub> bulk of AIMP 92901 and 3% to 34% more Zn for GB 8735. Clearly, the genetic gain observed in the C<sub>1</sub> (Fe) bulk was much larger in the 2007 post-rainy season.

In addition, 100 S<sub>1</sub> progenies from each of the three populations (CGP, ICTP 8203 and GGP bulk) were evaluated during the 2007 post-rainy and rainy seasons to initiate recurrent selection. ICTP 8203 progenies were early in flowering (40–46 days in post-rainy and 40–47 days in rainy season) when compared to CGP (44–52 days in post-rainy and 45–54 days in rainy season) and GGP progenies (43–51 days in post-rainy and 44–53 days in rainy season). Grain samples of ICTP 8203 progenies from the 2007 post-rainy season have been sent to CIP, Peru for grain Fe and Zn estimation through NIR (Near Infra Red) Reflectance method. Grain samples (25g each) from the remaining two populations evaluated during the 2007 post-rainy season and rainy season are yet to be analyzed for Fe and Zn content. ICTP 8203 is a commercial open-pollinated variety grown on 0.3 million ha in India. This variety has been found with high levels of grain Fe and Zn content. While a preliminary assessment of the effectiveness of recurrent selection to improve Fe and Zn content will be made from the 100-progeny trial mentioned, a much larger recurrent selection program has been planned to develop its improved version with high grain Fe and Zn content, and perhaps increasing its grain yield level as well. For this, 570 plants were selfed in a breeder seed production plot and S<sub>1</sub> seed were tested for Fe content using Perls Prussian Blue staining. Based on the staining results, 303 S<sub>1</sub> progenies staining deep to medium-blue (and hence likely to have high Fe content) were selected for field trial, and estimation of Fe and Zn content.

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### **Activity 5C.1.2: Conduct inheritance studies and develop mapping populations for Fe and Zn**

*Milestone 5C.1.2.1: Genetics of grain Fe and Zn established (BVSR, 2009)*

In order to investigate the genetics of grain Fe and Zn contents, crosses were made between adapted breeding lines and unadapted germplasm lines (contrasting for Fe and Zn contents) in three diallels in the 2006–07 post-rainy season. The three diallels (a 6 × 6 diallel with parents contrasting for grain Fe content, a 4 × 4 diallel with parents contrasting for grain Zn content and a 5 × 5 diallel with parents contrasting for both grain Fe and Zn-contents) will be evaluated in separate trials during the 2007 post-rainy season.

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*Milestone 5C.1.2.2: F<sub>6</sub> RILs from at least one cross developed (BVSR/CTH, 2009)*

A total of 11 parents contrasting for Fe and Zn were crossed in a diallel pattern to generate F<sub>1</sub>s. The parents are being genotyped for estimating parental diversity. Based on the genotyping results, crosses involving more diverse parents (contrasting for grain Fe and Zn) will be advanced to generate RILs.

BVS Reddy, A Ashok Kumar and CT Hash

## **II. Pearl millet**

**Output target 5C.1: Magnitude of variability for grain iron (Fe) and zinc (Zn) in more than 300 inbred lines, 50 improved populations, 400 germplasm accessions, and 40 commercial hybrids of pearl millet quantified, and at least three lines and three populations with high levels of Fe (65–75 ppm) and Zn (45–55 ppm) identified (2009)**

**Activity 5C.1.1: Evaluation of germplasm, breeding lines and improved populations for grain Fe and Zn contents**

*Milestone 5C.1.1.1: Variability for Fe and Zn in designated hybrid parents, population progenies and improved populations developed in Asia and African region quantified (KNR/RB/KLS, 2007)*

Grain iron and zinc contents in hybrid parents: Perl's Prussian blue staining method was used for initial screening of hybrid parents (99 designated B-lines and 93 restorer parents) for preliminary assessment of variability for Fe content among these parental lines. Of the 99 seed parents, 29 appeared to have high Fe content (18 with deep blue and 11 with medium blue color). Similarly, 23 of 93 restorer lines appeared to have high Fe content (10 with deep blue and 13 with medium blue color). In the light of large variability among the B- and R-lines, the open-pollinated grains from the 2005 rainy season were subjected for Atomic Absorption Spectrophotometry (AAS) estimation. Over three-fold variation for grain Fe content (28.0–101.0 ppm) and over two-fold variation for Zn content (26.6–67.2 ppm) was observed among R-lines. Highly significant positive correlation was observed between Fe and Zn content ( $r = 0.78$ ;  $P < 0.01$ ). The restorer parent IPC 1356, recorded the highest level of Fe content (101.0 ppm) and IPC 1650 had highest grain Zn (67.2 ppm) content. In general, most of the lines that developed deep blue color had high Fe content (57.8–101.0 ppm). B-lines are yet to be analyzed for these micronutrients.

The B- and R-lines that developed deep to medium blue colors on staining were field tested during the 2007 rainy season and grain samples were produced for AAS estimation. Selfed grain samples (50g each) were produced for AAS estimation and further evaluation during the 2008 summer season.

**Intra-population variability for Fe and Zn content:** Fifty  $S_1$  progenies derived from the four populations (ICTP 8203, CGP GGP and PVGGP) identified for high Fe and Zn from the 120-entry trial) were field tested during the 2006 rainy and postrainy season to determine the intra-population variability. Grains produced from these trials were analysed in 2007 for grain Fe and Zn density. Highly significant differences ( $P < 0.01$ ) were observed between the progenies derived from all the four populations, indicating the possibility of exploitation of intra-population variability for enhancing the levels of these micronutrients by recurrent selection, and deriving inbred lines with high Fe and Zn to be used as hybrid parents. Based on pooled data over two seasons, approximately two-fold variation for both grain Fe and Zn content in ICTP 8203 (56.1–127.7 ppm Fe and 41.9–93.4 ppm Zn), CGP (62.4–148.1 ppm Fe and 56.7–89.0 ppm Zn), GGP (42.1–146.0 ppm Fe and 33.5–85.1 ppm Zn) and PVGGP6 (35.6–120.5 ppm Fe and 29.7–88.6 ppm Zn) was observed. Highly significant and positive correlation was observed between Fe and Zn content in all the four populations ( $r = 0.66$  to  $0.85$ ;  $P < 0.01$ ).

Ten progenies of ICTP 8203 population had  $>100$  ppm Fe content (103.5–127.7 ppm) and 5 of these had  $>80$  ppm Zn content (81.6–93.4 ppm); 17 progenies from CGP population had  $>100$  ppm grain Fe content (100.6–148.1 ppm) and 5 of these had  $>80$  ppm Zn content (80.6–89.0 ppm). Similarly, in case of GGP, 21 progenies had  $>100$  ppm Fe (100.1–146.0 ppm) and 8 progenies had  $>80$  ppm Zn content (80.6–85.1 ppm); 11 progenies of PVGGP6 progenies had  $>100$  ppm Fe (100.7–120.5 ppm) and 6 progenies had  $>80$  ppm Zn content (80.4–88.6 ppm).

In order to get progenies with high Fe and Zn content, 570  $S_1$  progenies were produced from an open-pollinated variety 'ICTP 8203', with high Fe and Zn, to exploit intra-population variability for enhancing the levels of these micronutrients by recurrent selection, and deriving inbred lines with high Fe and Zn content. Preliminary assessment of variability for Fe content among progenies will be initially done by Perl's Prussian blue staining method and the resulting high Fe content progenies will be evaluated during the 2008 summer season.

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*Milestone 5C.1.1.2: Variability for Fe and Zn in inidi germplasm, core collection and commercial hybrids assessed (KNR/RB/HDU/KLS, 2008)*

**Evaluation of inidi germplasm for grain iron and zinc contents:** Grains of 313 *inidi* germplasm accessions (originating from several West African countries) were subjected to determination of grain Fe content by using Perl's Prussian blue staining method. Of these, 155 accessions showing deep to medium-deep blue on staining were field tested in two replications during the 2007 rainy and postrainy seasons. Laboratory analysis of grain Fe and Zn content from the 2007 postrainy season was completed at NIN, Hyderabad, India and the grain

samples produced (each 25 g) during the 2007 rainy season have been sent to NIN, Hyderabad and results are awaited.

Laboratory results from the grains produced during the 2007 post-rainy season showed large variability among *iniadi* accessions for both Fe (47.9–134.3 ppm) and Zn content (39.1–82.0 ppm) with a mean of 79.3 ppm for Fe and 59.9 ppm for Zn. Twelve accessions had >100 ppm Fe content and 8 accessions had >75 ppm Zn content. Except for four accessions that recorded <50 ppm Fe and eight accessions with <45 ppm Zn, remaining accessions had >50 ppm Fe and >45 ppm Zn. IP 17672 had the highest level of grain Fe (134.3 ppm) as well as Zn content (82.0 ppm). Highly significant ( $P < 0.01$ ) and positive correlation was observed between Fe and Zn content ( $r = 0.81$ ). The flowering time among the *iniadi* accessions varied from 37 to 58 days during the post-rainy season and 39 to 60 days during the rainy season.

**Evaluation of core collection for grain Fe and Zn content:** The *iniadi* germplasm is a good source for high grain Fe and Zn content. However, due to their genetical relatedness, the likelihood of finding different genes in this group for either Fe or Zn content is not very high. Thus, attempts are underway to explore new sources of germplasm accessions for higher micronutrient content in the non-*iniadi* groups of materials. A core collection of 504 accessions from 25 countries was screened using the Perls Prussian Blue staining technique. There were 166 accessions becoming medium to dark blue, indicating the possibility of these having high Fe content. These accessions were field tested during the 2007 post-rainy and rainy seasons. The time to flowering among the accessions varied from 46 to 78 days and 44 to 80 days during the 2007 post-rainy and rainy seasons, respectively. The grain samples produced (each 25g) from the 2007 post-rainy season have been sent to ICRISAT laboratory for grain Fe and Zn content estimation, and results are awaited.

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*Milestone 5C.1.1.3: G×E interaction for Fe and Zn assessed and lines stable for >70 ppm Fe and >50 ppm Zn identified (KNR/RB/KLS, 2009)*

Twenty-nine entries representing a wide range of Fe and Zn content (14 high, 8 medium, 6 low lines and an OPV check, WC-C 75) and selected from two seasons screening of a 120-entry trial, were field evaluated for G×E interaction at Patancheru in five different seasons (rainy and post-rainy seasons of 2004 and 2005, and post-rainy 2006). Grain Fe and Zn data from these five trials were subjected to stability analysis following the Eberhart and Russell model. Highly significant ( $P < 0.01$ ) differences were observed due to entries, environments, and entries × environment interaction, both for the Fe and Zn content, indicating the influence of change in environments on the performance of the entries for these two micronutrients. However, entries × environment (linear) was significant for only grain Zn content, implying that, in general, linear sensitivity of the different entries was variable with respect to environment, which was not so with grain Fe content. The correlation among the environments was highly significant ( $r = 0.73$  to  $0.96$ ;  $P < 0.01$  for Fe and  $r = 0.74$  to  $0.96$ ;  $P < 0.01$ ), suggesting, in general, a relatively consistent ranking of genotypes for both grain Fe and Zn content across the environments.

This stability trial of 28 entries was also field evaluated in 8 diverse locations of different agro-ecological conditions in India during the 2006 rainy season under the ICAR-ICRISAT partnership project to further investigate the stability of these lines for grain Fe and Zn content. The Fe and Zn estimation of grain samples produced from different locations are in progress.

Further, based on two seasons' data of a 69-population trial, 18 populations with diverse grain Fe and Zn density and two checks (WC-C 75 and RCB 2) were field tested during the 2006 rainy and 2007 post-rainy season for assessing the stability of grain Fe and Zn content among the populations. Significant differences existed among the populations and environments with respect to grain Fe and Zn content. Differential response of entries towards varying environments was evident as the genotype × environment interaction was significant for grain Fe and Zn content. The relative ranking of populations remained the same across the seasons as highly significant correlations were observed between seasons for both Fe ( $r = 0.69$ – $0.80$ ;  $P < 0.01$ ) and Zn content ( $r = 0.57$ – $0.60$ ;  $P < 0.01$ ). The same trial was also conducted in 6 different locations across India during the 2007 rainy season. The grain samples are yet to be received from different locations.

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**Output target 5C.2: Information on genetics and recurrent selection efficiency for grain Fe and Zn available (2009)**

### **Activity 5C.2.1: Conduct genetical studies and recurrent selection for grain Fe and Zn contents and develop mapping populations**

*Milestone 5C.2.1.1: Inheritance of Fe and Zn, and relationship between the parental lines and hybrids for these traits determined (KNR/RB/KLS, 2009)*

Utilization of the variability in breeding hybrid parents and populations with enhanced levels of micronutrients can be more effective following efficient breeding methodologies based on the nature of inheritance. In an attempt towards this direction, a set of 30 S<sub>1</sub> progenies from two populations (PVGGP6 and IAC-ISC-TCP1) was field evaluated during the 2007 postrainy and rainy seasons for grain yield and other agronomic traits. Progenies derived from PVGGP6 flowered early (43–46 days in the 2007 postrainy and 43–48 days in the 2007 rainy season) when compared to progenies from IAC-ISC-TCP1 (55–60 days in postrainy and 55–62 days in rainy season). PVGGP 6 progenies showed large variability for plant height (14–193 cm in postrainy and 175–270 cm in rainy season), panicle length (25–42 cm in postrainy and 30–46 cm in rainy season) and grain yield (823–1988 kg ha<sup>-1</sup> in postrainy season), whereas IAC-ISC-TCP1 progenies showed a wider range for plant height (126–173 cm in postrainy and 183–249 cm in rainy), panicle length (17–28 cm in postrainy and 17–30 cm in rainy season) and grain yield (944–1928 kg ha<sup>-1</sup> in postrainy season). Grain samples produced (50 g each) from both the seasons are yet to be analyzed for Fe and Zn content to assess the relationship of these two micronutrients with grain yield and other agronomic traits.

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*Milestone 5C.2.1.2: Effectiveness of S<sub>1</sub> recurrent selection for Fe and Zn, and its effect on grain yield and other agronomic traits in four populations quantified (KNR/RB/KLS, 2012)*

Earlier research results showed that the heritability of grain Fe and Zn was a high, there was highly significant positive correlation between Fe and Zn, and that there was either positive or no correlation of Fe and Zn with grain size. As a consequence, recurrent selection for grain Fe and Zn is likely to be fairly effective, with no adverse effect on grain yield. This hypothesis is being tested on five populations that have been identified as having high levels of grain Fe and Zn contents.

Two open-pollinated varieties (GB 8735 released in several countries in the Western and Central Africa, and AIMP 92901 released in India) for which the progenies bred for restorer line development were available, were taken up for an initial pilot study. From amongst 50 progenies evaluated in each population, nine progenies with high grain Fe and Zn content were selected separately from both AIMP 92901 (81.5–104.0 mg kg<sup>-1</sup> Fe and 57.0–68.0 mg kg<sup>-1</sup> Zn) and GB 8735 (78.5–104.5 mg kg<sup>-1</sup> Fe and 57.0–59.5 mg kg<sup>-1</sup> Zn), and random mated (half diallel) in the 2006 post rainy season. The C<sub>1</sub> cycle bulks produced from progenies selected for high iron content—C<sub>1</sub> (Fe), and the one produced from progenies selected for high zinc content—C<sub>1</sub> (Zn), and original bulks (C<sub>0</sub>) of both the populations were evaluated for grain yield and agronomic traits in four replications during the 2006 rainy and 2007 post rainy seasons. The grain samples produced from both the seasons were analyzed at ICRISAT laboratory to estimate Fe and Zn content. The differences among the population bulks and their interaction with the environments were highly significant (P < 0.01) both for grain Fe and Zn contents.

Nine progenies with high grain Fe and Zn content were selected separately from both AIMP 92901 (81.5–104.0 mg kg<sup>-1</sup> Fe and 57.0–68.0 mg kg<sup>-1</sup> Zn) and GB 8735 (78.5–104.5 mg kg<sup>-1</sup> Fe and 57.0–59.5 mg kg<sup>-1</sup> Zn), and random mated (half diallel) in the 2006 postrainy to initiate recurrent selection. The C<sub>1</sub> cycle bulks produced from progenies selected for high iron content—C<sub>1</sub> (Fe), and the one produced from progenies selected for high zinc content—C<sub>1</sub> (Zn), and original bulks (C<sub>0</sub>) of both the populations were evaluated in four replications during the 2006 rainy and 2007 postrainy seasons. The grain samples produced from both the seasons were analyzed at ICRISAT-Patancheru laboratory to estimate Fe and Zn content. The differences among the population bulks and their interaction with the environments were highly significant (P < 0.01) both for grain Fe and Zn contents.

Based on mean performance across the two environments, C<sub>1</sub> (Fe) bulks had 21–22% higher grain Fe content than the C<sub>0</sub> bulks of both AIMP 92901 (66 ppm) and GB 8735 (62 ppm). Larger genetic gains with 39–40% higher Fe was observed in C<sub>1</sub> (Fe) bulks than in the C<sub>0</sub> bulks of AIMP 92901 and GB 8735 in the 2007 postrainy season with a trial mean of 54.4 ppm for AIMP 92901 and 50.3 ppm for GB 8735, than in the 2006 rainy season that, although had higher trial mean (84.5 ppm for AIMP 92901 and 79.6 ppm for GB 8735), showed



genetic gain of only 11–12%. Further, the C<sub>1</sub> (Zn) bulk of AIMP 92901 had 73 ppm Fe (10% higher than C<sub>0</sub> bulk) and this difference was statistically significant. However, there was no significant difference between the C<sub>1</sub> (Zn) and C<sub>0</sub> bulk for Fe in GB 8735. Largest genetic gains in C<sub>1</sub> (Zn) bulk for Fe (27% in AIMP 92901 and 23% in GB 8735) were observed in 2007 post-rainy season and practically no gain was observed in the 2006 rainy season. Based on the mean performance across these two environments, comparison of C<sub>1</sub> (Zn) and C<sub>1</sub>(Fe) bulks with C<sub>0</sub> bulks showed that selection for Fe was at least as or even more effective than direct selection for Zn content. For instance, C<sub>1</sub> (Fe) bulks had 12% more Zn than C<sub>0</sub> bulk in AIMP 92901 (50 ppm) and 18% more in GB 8735 (45 ppm), while the C<sub>1</sub>(Zn) bulk had 7% more Zn than C<sub>0</sub> bulk in AIMP 92901 and 15% more Zn in GB 8735. The genetic gains detected for Zn were more consistent across the environments for the C<sub>1</sub>(Zn) bulk, with 7% more Zn than the C<sub>0</sub> bulk of AIMP 92901 and 12–18% more Zn for GB 8735. The C<sub>1</sub>(Fe) bulks had large variation in its Zn content across the environments, with 7% less to 35% more Zn as compared to C<sub>0</sub> bulk of AIMP 92901 and 3% to 34% more Zn for GB 8735. Clearly, the genetic gain observed in the C<sub>1</sub>(Fe) bulk was much larger in the 2007 post-rainy season.

In addition, 100 S<sub>1</sub> progenies from each of the three populations (CGP, ICTP 8203 and GGP bulk) were evaluated during the 2007 post-rainy and rainy seasons to initiate recurrent selection. ICTP 8203 progenies were early in flowering (40–46 days in post-rainy and 40–47 days in rainy season) when compared to CGP (44–52 days in post-rainy and 45–54 days in rainy season) and GGP progenies (43–51 days in post-rainy and 44–53 days in rainy season). Grain samples of ICTP 8203 progenies from the 2007 post-rainy season have been sent to CIP, Peru for grain Fe and Zn estimation through NIR (Near Infra Red) Reflectance method. Grain samples (25g each) from the remaining two populations evaluated during 2007 post-rainy season and rainy season are yet to be analyzed for Fe and Zn content.

ICTP 8203 is a commercial open-pollinated variety grown on 0.3 million ha in India. This variety has been found having high levels of grain Fe and Zn content. While a preliminary assessment of the effectiveness of recurrent selection to improve Fe and Zn content will be made from the 100-progeny trial mentioned above, a much larger recurrent selection program has been planned to develop its improved version with high grain Fe and Zn content, and perhaps increasing its grain yield level as well. For this, 570 plants were selfed in a breeder seed production plot during the 2007 rainy season and S<sub>1</sub> seeds were tested for Fe content using Perls Prussian Blue staining method. Based on the staining results, 303 S<sub>1</sub> progenies staining deep to medium-blue (and hence likely to have high Fe content) were selected, which will be evaluated for grain Fe and Zn content.

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**Effect of dwarfing gene on grain Fe and Zn content:** In pearl millet, most of the hybrid parents have d<sub>2</sub> dwarfing gene, which is more suitable for mechanized agriculture. Hence, to investigate the effect of dwarfing gene (d<sub>2</sub>) on Fe and Zn content in pearl millet grain, 12 pairs of near-isogenic tall and dwarf lines were evaluated in three replications during the 2007 rainy season. Selfed grain samples (each 50g) were produced for laboratory analysis of grain Fe and Zn content.

**Inbreeding depression for grain Fe and Zn content:** The earlier genetical studies showed that the inheritance of grain Fe and Zn content was largely controlled by additive gene effects. Hence, to further investigate the relative importance of additive and non-additive gene effects on grain Fe and Zn content, four sets of populations, which consisted of the original population, and their four generations of selfed bulks were evaluated in three replications during the 2007 rainy season. The objective of the study is to determine the level of inbreeding depression for grain Fe and Zn content from original population to advance generations of selfing. Selfed grain samples (50g each) were produced for laboratory analysis of grain Fe and Zn content.

**Inheritance of grain Fe and Zn content:** Line × Tester crosses were made between five designated B-lines with high Fe (59–66 ppm) and Zn content (44–50 ppm), and 12 pollen parents that had 70–130 ppm Fe and 54–90 ppm Zn. The resulting hybrids were evaluated along with the parental lines to determine the relationship between performance *per se* and general combining ability for Fe and Zn content. Selfed grain samples (each 50g) were produced from parents and hybrids for laboratory analysis of grain Fe and Zn content. In another study, 400 testcross hybrids were developed by crossing 8 designated seed parents (with high Fe: 59–72 ppm Fe and Zn: 44–64 ppm) with 102 pollen parents (with high Fe: 67–151 ppm and Zn: 48–107 ppm) for assessing the hybrid performance for grain Fe and Zn content.

Inter-laboratory correlation for Fe and Zn content: Sibbed seed samples of 20 populations selected from the set 2 trial consisting of 69 populations during the 2005 post-rainy season were screened for Fe and Zn content across

three laboratories (NIN, Hyderabad, India; Waite, Australia; and Central Analytical Laboratory, ICRISAT, Patancheru, India) for validating the repeatability and consistency of Fe and Zn estimates across the three laboratories. There were highly significant ( $P < 0.01$ ) and positive correlations between Fe estimates from NIN and those from Waite ( $r = 0.96$ ) and ICRISAT ( $r = 0.89$ ); as well as ICRISAT and Waite lab ( $r = 0.83$ ). Similarly for Zn estimates, highly significant ( $P < 0.01$ ) and positive correlations were found between NIN and those from Waite ( $r = 0.91$ ) and ICRISAT ( $r = 0.88$ ); as well as ICRISAT and Waite lab ( $r = 0.82$ ).

Eighteen different populations/breeding lines with high Fe and Zn levels were selected and seed samples were multiplied for assessing Al and Ca in these lines.

**Standardizing staining method for grain Zn content:** A staining method for grain Fe content has been standardized that serves as a qualitative selection criterion for grain Fe in pearl millet. This method is efficient in distinguishing lines with high and low Fe content. While screening a large number of germplasm or breeding lines, this method has proved to be efficient in at least discarding lines with low Fe content. Similar attempts are underway to standardize a method for grain Zn content. Preliminary results showed varying intensity of red color in genotypes with medium to high Zn content. The reliability of distinguishing high Zn lines from the medium Zn lines was not yet satisfactory. However, low Zn lines can be reliably sorted out, as they developed no color. Further standardization of the protocol to distinguish between high Zn lines and medium Zn lines continues.

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*Milestone 5C.2.1.3: Genotypic and phenotypic data on two  $F_6$  RIL mapping populations generated (CTH/SS/KNR, 2010)*

No report yet

*Milestone 5C.2.1.4: Sorghum and pearl millet assessed for mycotoxins (FW, 2010)*

**Aflatoxin contamination in sorghum and pearl millet:** Sorghum and pearl millet grain samples from farmer's fields and storage were collected from different project clusters. Aflatoxins and fumonisins were detected by enzyme-linked immunosorbent assay (ELISA). From the on-farm trials, about 60 sorghum grain samples at harvest stage as well as from farmer storage were collected from 10 villages in Udityal cluster, Mahabubnagar district, Andhra Pradesh, India. Similarly, 149 sorghum samples at harvest were collected from 13 villages representing 3 clusters in Parbani and Beed districts of Maharashtra state, India. Overall, 209 sorghum grain samples were collected from 209 farmers from 23 villages in Maharashtra and Andhra Pradesh. From Palawai cluster (Mahabubnagar district, Andhra Pradesh) about 143 pearl millet samples (66 samples at harvest from farmer's fields and 77 storage samples) from 9 villages were collected. From each field or storage, five panicles or grain samples were collected to market a 250 g representative composite sample for mycotoxin analysis.

Thirty sorghum samples collected at harvest from 30 farmers' fields representing 5 villages and another 30 samples from farmer storages were analyzed by ELISA for aflatoxin and fumonisin contamination. Aflatoxin contamination ranged from 0 to 362  $\mu\text{g}/\text{kg}$  in field samples, and storage samples showed 0 to 317  $\mu\text{g}/\text{kg}$  in Udityal cluster of Mahabubnagar district. Samples collected from 13% of the fields contained  $>30 \mu\text{g}/\text{kg}$  of aflatoxin. Aflatoxin levels were high (40–92  $\mu\text{g}/\text{kg}$ ) in 42% of the villages (Udityal, Chiuduru, Veerannapalli, Macharam and Nerellapalli). There was not much difference in aflatoxin contamination in field samples and storage samples. Fumonisin contamination in sorghum samples ranged from 0 to 254  $\mu\text{g}/\text{kg}$  and samples from 15% of the fields contained  $>100 \mu\text{g}/\text{kg}$  across fields and villages. Samples, which contained high levels of aflatoxin, did not have high level of fumonisin and vice-versa.

Sorghum samples collected at harvest stage from 13 villages under 3 clusters in Parbani and Beed contained aflatoxin from 0 to 63  $\mu\text{g}/\text{kg}$ . About 77% of the samples were free from aflatoxin and  $<1\%$  samples contained higher levels ( $>30 \mu\text{g}/\text{kg}$ ) of aflatoxin. Fumonisin contamination was from 0 to 441  $\mu\text{g}/\text{kg}$ , and 26% of the samples showed  $>100 \mu\text{g}/\text{kg}$ .

In pearl millet, 66 samples from fields and 77 samples from storage from nine villages of Palawai cluster were analyzed for mycotoxin contamination. Aflatoxin concentration ranged between 0–32  $\mu\text{g}/\text{kg}$  across the field and storage samples. A large number of samples ( $>83\%$ ) were free from aflatoxin and only one sample (0.7%) showed  $>30 \mu\text{g}/\text{kg}$  aflatoxin. Fumonisin contamination ranged from 0–26  $\mu\text{g}/\text{kg}$  and none of the samples contained  $>100 \mu\text{g}/\text{kg}$ .

Analysis of sorghum and pearl millet clearly indicated that mycotoxin contamination was higher in sorghum than in pearl millet. Sorghum grown in different agro-ecological zones showed variable levels of contamination, and sorghum grown in Udityal cluster of Andhra Pradesh contained higher levels of mycotoxin contamination.

Farid Waliyar

## List of Publications in 2007

### Abstracts:

**Rao VP, Kadwani DL, Sharma YK and Thakur RP.** 2007. Virulence diversity among isolates of the pearl millet downy mildew pathogen, *Sclerospora graminicola* from Gujarat. Presented at the National Symposium on Plant Pathogens: Exploitation and Management during the Indian Phytopathological Society Annual Meeting, 16-18 January 2007 at Rani Durgawati University, Jabalpur, MP, India. Abstract #IPS 62, 29-30pp.

**Reddy BVS, Ashok Kumar A and Dar WD.** 2007. Overview of sweet sorghum breeding at ICRISAT: Opportunities and constraints. Abstract submitted for the conference on Global consultation on pro-poor sweet sorghum development for bio-ethanol production and introduction to tropical sugar beet agenda, 8-9 November, Rome, Italy

**Reddy BVS, Ashok Kumar A and Sanjana Reddy P.** 2007. Sweet sorghum: A dryland-adapted, pro-poor bioethanol feed stock yielding both grain and fuel. USDA global conference on agricultural biofuels: Research and Economics. Agricultural Production and Biomass conversion. 20-22 August 2007, at Minneapolis, Minnesota, USA.

**Reddy BVS, Ashok Kumar A, Parthasarathy Rao P and Sanjana Reddy P.** 2007. Sweet sorghum domains, hybrid sweet sorghum seed production and agronomic practices: An overview. Abstract submitted for the conference on Global consultation on pro-poor sweet sorghum development for bio-ethanol production and introduction to tropical sugar beet agenda, 8-9 November, Rome, Italy

### Books:

**Khairwal IS, Rai KN, Diwakar B, Sharma YK, Rajpurohit BS, Nirwan B and Bhattacharjee R.** 2007. Pearl Millet: Crop Management and Seed Production Manual. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 108 pp.

**Saxena KB.** 2006. Seed Production System in Pigeonpea. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502 324, Andhra Pradesh, India. 76 pp.

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**Saxena KB and Kumar RV.** 2006. Hybrid Pigeonpea: Research and Development. Pages 167-207 in Hybrid Parents Research at ICRISAT (Gowda CLL, KN Rai, Belum VS Reddy and KB Saxena, eds.). International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 234, Andhra Pradesh, India.

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### Brochures/Pamphlets:

**Saxena K.B.** 2006. Hybrid Pigeonpea – Seeds of Excellence. ICRISAT, Patancheru, 8 pp.

**Sharma R.** 2007. Selection of the Fittest. SATrends, August.

### Conference Papers:

**Alur Ashok S, Ravinder Reddy Ch, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Markets access for poverty reduction and improved livelihoods of small and marginal scale dry land farmers. Presented at the International Conference on Ethnographic Discourse of the Other, 3-5 July 2007, University of Hyderabad, Hyderabad, Andhra Pradesh, India

**Gulia SK, Hash CT, Thakur RP, Breese WA and Sangwan RS.** 2007. Mapping new QTLs for improvement of downy mildew resistance in pearl millet. Pages 373-386 in proceedings of the International Conference on Sustainable Crop Production in Stress Environments: Genetic and Management Options, 9-12 February 2005

(Singh DP, Tomar VS, Behl RK, Upadhyaya SD, Bhale MS and Khare D. eds.). Agrobios (International), Jodhpur, Rajasthan, India.

**Parthasarathy Rao P, Alur Ashok S, Reddy Ch Ravinder, Reddy BVS and Gowda CLL.** 2007. Improving livelihoods of small and marginal scale farm producers in Asia through institutional innovations. Presented at the 3-day International Conference on Ethnographic Discourse of the Other, 3-5 July 2007, University of Hyderabad, Hyderabad, Andhra Pradesh, India

**Parthasarathy Rao P, Ashok S Alur, Ravinder Reddy Ch, Reddy BVS, and Gowda CLL.** 2007, Improving livelihoods of small and marginal scale farm producers in Asia through institutional innovations. Paper presented at the International Conference on Ethnographic discourse of the Other, 3-5 July 2007, University of Hyderabad, Hyderabad, Andhra Pradesh, India.

**Rajashekar Reddy A, Gowda CLL, Reddy BVS, Rai KN, Farid Waliyar, Ashok S Alur, and Ravinder Reddy Ch.** 2007. Paper presented at Asian Pacific Poultry Conference (APPC 2007), at Bangkok, 5-6 March, 2007.

**Ravinder Reddy Ch, Alur Ashok S, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Building social capital for improving the livelihoods of small and marginal farmers in SAT regions of Asia. Paper presented at the International Conference on Ethnographic Discourse of the Others, 3-5 July 2007, University of Hyderabad, Hyderabad, Andhra Pradesh, India

**Ravinder Reddy Ch, Ashok S Alur, Reddy BVS, Parthasarathy Rao P and Gowda CLL.** 2007. Building human and social capital for improving the livelihoods of small and marginal farmers in SAT regions of Asia. Paper presented in International conference on Ethnographic Discourse of the Others, 3-5 July 2007 at University of Hyderabad, Hyderabad, Andhra Pradesh, India.

**Reddy BVS, Ramesh S and Ashok Kumar A.** 2007. Sweet sorghum: A water saving bio-energy crop. Paper presented at the International Conference on Linkages between Energy and Water Management for Agriculture in Developing Countries, 29-31 January 2007.

**Reddy BVS.** 2007. The technology dimensions of biofuel development. Proceedings of the Planning Workshop on Strategies and Options for Integrating Biofuels and Rural Renewable Energy for Poverty Reduction, Greater Mekong Subregion Economic Cooperation Program Working Group in Agriculture (WGA) Biofuel and Rural Renewable Energy Initiative, 11-13 June 2007, Bangkok, Thailand.

**Thakur RP.** 2007. Host-plant resistance to diseases: potential and limitations. Pages 36-38 in Extended Summaries of National Conference on Organic Waste Utilization and Eco-friendly Technologies for Crop Protection. Plant Protection Association of India, 15-17 March 2007, Hyderabad. (Lead paper-13).

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**Saxena KB, Dalvi VA and Heraldo L.** 2006. Pigeonpea – A Potential Dryland Crop for the Philippines. Paper presented, during PHILARM National Convention 18-21 April, 2006, Batac, Ilocos Norte, The Philippines

**Saxena KB.** 2006. Breeding hybrids for enhancing productivity in pigeonpea. Paper presented at meeting organized by Maharashtra State Seed Corporation, Akola, December 8, 2006.

**Saxena KB and Gowda CLL.** 2006. Evolution of commercial pigeonpea hybrids in India. Paper presented at Golden Jubilee and AE-BRNS Life Sciences Symposium, December 18-20, 2006 at Bhabha Atomic Research Center, Mumbai, India.

#### **Edited Book/Information Bulletin:**

**Borikar ST, Belum VS Reddy, Ashok S Alur, Ch Ravinder Reddy, Sanjay Birajadar, Kalapande H V, and Tripathi CMS.** 2007. Rainy season sorghum production technologies for dryland areas of Maharashtra. Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. 16 pp.

**Rai KN, Alur Ashok S, Ravinder Reddy Ch, Kalapande HV, Sanjay N Biradar, Varaprasad Reddy KM and Rajashekhar Reddy A.** 2007. Pearl millet production technologies for Andhra Pradesh and Maharashtra. Global Theme on Crop Improvement, International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. 16 pp.

**Reddy BVS, Ravinder Reddy Ch, Alur Ashok S, Varaprasad Reddy KM and Bhubeshkumar R.** 2007. Improved production technologies for rainy season sorghum in Andhra Pradesh. Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. 18 pp.

**Saxena KB.** 2006. Hybrid pigeonpea seed production manual. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502 324, Andhra Pradesh, India. 32 pp. ISBN 92-9066-493-2. Order code IBE074.

**Sharma HC, Alur Ashok S, Ravinder Reddy Ch, Jayaraj, Varaprasad VJ, Varaprasad KM, Reddy BVS and Rai KN.** 2007. Management of sorghum and pearl millet pests in bulk storage. Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. 16 pp.

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#### **Flvers/Booklet:**

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**Reddy BVS.** BioPower sweet sorghum: Empowering dryland poor (frequently asked questions), Pages 1-14.

**Reddy BVS, Ravinder Reddy Ch, Ashok S Alur, Varaprasad Reddy K M and Bhubeshkumar R.** 2007. Improved Production Technologies for Rainy Season Sorghum in Andhra Pradesh ; Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru- 502324, Andhra Pradesh, India.18 pp.

**Borikar S T, Reddy BVS, Ashok S Alur, Ravinder Reddy Ch, Sanjay Birajadar, Kalapande HV and Tripathi CMS.** 2007. Rainy Season Sorghum production Technologies for Dryland Areas of Maharashtra ; Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru- 502324, Andhra Pradesh, India.16 pp.

**Sharma HC, Ashok S Alur, Ravinder Reddy Ch, JaiRaj, Varaprasad V J, Varaprasad KM, Reddy BVS and Rai KN.** 2007. Management of Sorghum and Pearl Millet Pests in Bulk Storage. Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru- 502324, Andhra Pradesh, India.16 pp.

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**Thines Marco, Göker Markus, Telle Sabine, Ryley Malcolm, Mathur Kusum, Narayana YD, Spring Otmar, and Thakur RP.** Phylogenetic relationships of graminicolous downy mildews based on coxII sequence data. *Mycological Research* (Accepted, Aug 2007)

**Velu G, Rai KN, Muralidharan V, Kulkarni VN, Longvah T and Raveendran TS.** 2007. Prospects of breeding biofortified pearl millet with high grain iron and zinc contents. *Plant Breeding* 126(2):182-185.

**Velu G, Rai KN, Muralidharan V, Longvah T, Sahrawat KL, Raveendran TS and Sumalini K.** Variability for grain iron and zinc content in pearl millet populations. *Field Crops Research* (submitted).

#### **Newsletter Articles:**

**Reddy Belum VS, Sharma HC, Thakur RP, Ramesh S and Kumar AA.** 2007. Characterization of ICRISAT-bred sorghum hybrid parents (Set II). *International Sorghum and Millets Newsletter* 48 (special Issue(Sharma HC, ed.): 1-123.

**KN Rai, CT Hash, AK Singh and G Velu.** Adaptation and quality traits of a germplasm-derived commercial seed parent of pearl millet. *International Plant Genetic Resources Newsletter*. (accepted)

**Ravinder Reddy Ch, Reddy, BVS, Alur Ashok S, Ashok Kumar A and Sanjana Reddy P.** 2007. Effect of improved crop production technologies in improving sorghum productivity in rainfed areas of Mahabubnagar District in Andhra Pradesh. . *e-Journal of SAT Agricultural Research*. (<http://www.icrisat.org/journal/>), Vol 5, Issue 1.

**Reddy BVS, Sharma HC, Thakur RP, Ramesh S and Ashok Kumar A.** 2007. Characterization of ICRISAT-bred sorghum hybrid parents. Special Issue. *International Sorghum and Millets Newsletter* 48: 1-123.

#### **Posters/Oral Presentations:**

**Ashok Kumar A, Sanjana Reddy P, Reddy BVS, Sahrawat KL and Parthasarathy Rao P.** 2007. Exploring the core germplasm for grain Fe and Zn content, and estimating the influence of soil micronutrient levels and soil types on their stability. Poster presented at the 'Zinc Crops 2007' Conference, 24-26 May 2007, Istanbul, Turkey.

**Parthasarathy Rao P, Gurva Reddy, Reddy BVS, Ravinder Reddy Ch and Gowda CLL.** 2007. Enhancing livelihoods of small-scale sorghum producers in India: Innovation through a coalition approach. Poster presented in GFAR 2006 Triennial Conference at New Delhi. *GFAR Newsletter* 01:2007.



**Ch Ravinder Reddy, Rajashekhar Reddy, Ashok S Alur, Farid Waliyar, CLL Gowda, Belum VS Reddy and Rai KN.** 2007. Poster on Mycotoxins in sorghum and pearl millet: Ill effects on human and animal health and their management. Global Theme on Crop Improvement, International Crops Research Institute for the Semi Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.

**Reddy BVS.** 2007. Meeting with members of British Petroleum – Biofuels technical team, 16 August 2007.

**Reddy BVS.** 2007. Planning workshop on Strategies and options for integrating biofuels and rural renewable energy for poverty reduction, 11-13 June 2007, Bangkok, Thailand.

**Reddy BVS.** 2007. Expert consultation on Biofuels (Co-sponsored by APAARI, IRRI, CIMMYT, and ICRISAT), IRRI, Los Banos, Philippines, 27-29 August 2007 and presented on “Biofuel crops for dry lands: sweet sorghum, jatropha and pongamia”.

**Reddy BVS.** 2007. USDA Global conference on Agricultural Biofuels, USA, 20-22 August 2007

**Reddy BVS.** 2007. Global consultation on pro-poor sweet sorghum development for bio-ethanol production and introduction to tropical sugar beet agenda, 8-9 November, Rome, Italy and presented two presentations on “Overview of sweet sorghum breeding at ICRISAT: opportunities and constraints” and “Hybrid sweet sorghum production systems overview, including global mapping of sweet sorghum growing areas and its adaptability, especially in comparison with sugarcane”.

**Reddy BVS.** 2007. Next Biofuels technologies, 25-26 October, Beijing, China and presented on sweet sorghum based Biofuels project and case study in Andhra Pradesh, India.

**Reddy BVS.** 2007. Stakeholders’ workshop of NAIP Consortium partners organized at ICRISAT on 5 June 2007.

**Reddy BVS.** 2007. Monitoring & Evaluation workshop conducted by NAIP on 9-10 August 2007 at NAARM, Hyderabad and presented the M & E variables developed for the Sweet sorghum value chain development.

**Reddy BVS.** 2007. Training workshop on “Reporting climate change in Africa” in Nairobi, Kenya on 20 September 2007.

**Reddy BVS.** 2007. Coordination of the compilation of ‘Crop Adaptation to Climate Change – a center-wide strategy paper.

**Reddy BVS.** 2007. Genetic and cytoplasmic diversification of pearl millet hybrid parents : CCER panel, 7-11 May 2007, Patancheru

**Reddy BVS.** 2007. Prospects of sorghum and pearl millet for grain and fodder production in the CAC region. 10<sup>th</sup> CGIAR-CAC Steering Committee Meeting 29-30 May 2007, Dushanbe, Tajikistan.

**Rai KN.** 2007. Adaptation and yield potential of pearl millet for grain and fodder production. ICBA-organized workshop on “ Production and utilization of salt-tolerant forage crops/halophytes”, 5 June 2007, Samarkand, Uzbekistan

**Rai KN.** 2007. Crop diversification and value addition-role for ICRISAT mandate crops. CII –organized “Agri-Colloquium – Towards Value Added Agriculture - Evolving an Agro-vision for South India”, 13 October 2007, Hyderabad.

**Rai KN.** 2007. Pearl millet hybrid parents research at ICRISAT. Faculty of Plant Breeding, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. 24 April, 2007

**Rai KN.** 2007. Genetic variability and gene action for grain iron and zinc contents in pearl millet. HarvestPlus and India Biofortification Group Meeting, 18-22 March 2007, New Delhi.

**Rai KN.** 2007. Variability, inheritance and character association of grain iron and zinc density in earl millet. Gates Foundation HarvestPlus Assessment Meeting, 12-14 September 2007, CIAT, Cali, Columbia.

**Reports:**

**Ravinder Reddy Ch, Reddy BVS, Alur Ashok S, Ashok Kumar A and Sanjana Reddy P.** 2007. Effect of Improved Crop Production Technologies in Improving Sorghum Productivity in Rain fed Areas of Mahabubnagar District in Andhra Pradesh. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

## Project 6

### Producing More and Better Food at Lower Cost of Stable Open-Pollinated Cereals and Legumes (Sorghum, Pearl Millet, Pigeonpea, Chickpea and Groundnut) Through Genetic Improvement in the Asian SAT

*MTP output target 2007 6.1.1 GN 100 transgenic events of groundnut with TSVcp gene developed and screened in contained greenhouse*

Groundnut stem necrosis disease (GSND) caused by TSV has emerged as a serious problem on groundnut in Andhra Pradesh and Karnataka in India. All the currently grown groundnut varieties are susceptible to this virus. A biotech approach has been initiated to engineer resistance to TSV in groundnut by using the TSV coat protein (TSVcp) gene through *Agrobacterium tumefaciens*-mediated genetic transformation where several (112) putative transgenic events of popular groundnut cultivars JL 24, TMV 2, and ICGV 91114 were developed. PCR analysis confirmed integration of TSV CP transgene in 92 out of 112 events developed (73.6%). Further, ELISA/western analysis showed significant expression of CP in at least 32 transgenic events. More recently, the TSVCP gene driven by the CaMV 35S promoter was also sub-cloned into the pZP100 vector (Marker-free) and mobilized onto *Agrobacterium tumefaciens* strain C58. The generation of marker-free transgenic plants of groundnut with this vector has been initiated.

Leaf material from each progeny was collected prior to virus challenging, and tested by PCR analysis using TSVcp specific primers to determine the segregation pattern. In a batch-wise screening (10 events per batch), progenies from 22 transgenic events were evaluated for virus protection under contained greenhouse conditions. At the 3-leaf growth stage (8 - 10 day old plants), the test plants along with susceptible controls (JL 24) were dusted with carborandum and inoculated by standard mechanical sap inoculation procedure using 1:30 (w/v) TSV-affected French bean leaf sap extracts. After inoculation, plants were washed with tap water to remove excess carborandum. All test plants and controls developed necrotic symptoms 6 days after inoculation. Symptoms observed included veinal necrosis and stem necrosis, at 10 - 12 days after inoculations. Test plants were subsequently monitored at weekly intervals for virus spread and symptoms. These plants were tested by DAC ELISA for the presence of virus. All the inoculated plants developed necrotic symptoms on the inoculated leaves 7 days post-inoculation and tested positive to TSV with ELISA. Progenies from 7 events (31B, 47F, 48A, 48D, 48E, 48F, 1-1, 1-4, 4-6, 9-2, 9-3, 9-4 and 30-6) did not display any systemic symptoms, confirmed by negative results when tested by DAC ELISA. The fact that TSV was detected in the inoculated leaves of these plants and the lack of virus in the subsequently emerged leaves suggests blockage in the systemic spread of virus which seems to be responsible for the virus resistance. Progenies from 6 events delayed symptom expression by 2 to 3 weeks, compared to control groundnut plants. These plants apparently had normal growth pattern. It is likely that these plants may also have some resistance. A comprehensive evaluation of these events is being continued and trials will be repeated with event numbers 48, 1 and 9 to confirm the above results. At present, 20 additional events are under screening process in contained greenhouse conditions.

*MTP output target 2007 6.1.1 CP: 50 transgenic events of chickpea with Bt genes developed and screened in contained greenhouse*

In our ongoing efforts to develop transgenic plants of chickpea engineered for resistance to *Helicoverpa armigera*, several *Bt* genes have been used through *Agrobacterium tumefaciens*-mediated genetic transformation of popular chickpea cultivar C 235 using the axillary meristems as the explants. For efficient expression of *cryIAC* gene in chickpea, binary vectors with different promoters were used. Chickpea transgenics are being developed using dicot codon optimized *Bt cryIAC* gene constructs under the influence of Ubiquitin (pPZP200) and CaMV35S promoters (PRD 400). About 35 independent transgenic events have been produced and transferred to greenhouse. Molecular characterization of these plants is underway.

Chickpea transgenics carrying the *Bt cryIAb* or *cryIAC* genes independently are under evaluation for resistance to *Helicoverpa armigera* in the contained greenhouse. A total of 55 independent transgenic events have been produced and advanced to T1 generation. The transgenic plants have been analyzed for integration of transgene by PCR, and also characterized for expression of the *Bt* genes using ELISA. Twenty-one events with 8 replicates of each in T1 generation were sown in greenhouse and evaluated using ELISA and PCR. Preliminary bioassay for resistance to *Helicoverpa* using the leaf is in progress.

Besides, codon-optimized synthetic *cryIAC* genes for its optimal expression in chickpea using codon usage frequencies derived from the gene sequences available for various legumes (such as chickpea, pigeonpea, soybean, pea and *Medicago*) have been carried out for eventual production of events resistant to insects. A *cryIAC* gene sequence with enhanced GC content which has been modified to eliminate potential polyadenylation termination signals driven by both Ubiquitin and CaMV35S promoters, is being sub cloned into cloning/expression vectors to enhance the expression of *Bt* cry toxins in legume plants.

KK Sharma and P Bhatnagar-Mathur

*MTP output Target 2007 6.1.1 SO: Ten sweet sorghum lines with high biomass and tolerance to stem borer and foliar diseases developed*

Downy mildew resistance in sweet sorghum hybrid parent lines: Twenty B-lines and 16 R-lines along with one variety (SSV 84) and one hybrid (NSSH 104) were evaluated for resistance to sorghum downy mildew using the sandwich technique under greenhouse conditions during August 2007. A known DM resistant line, QL 3 and 3 susceptible lines (IS 3089, H 112 and 296B) were included as checks. The lines were evaluated in 3 replications, one pot (15 cm dia) per replication, with 30 - 35 seedlings per pot. Downy mildew incidence was recorded 14 days after inoculation. Of the 20 B-lines tested, one B-line (ICSB 690) was disease free, whereas, ICSB 565 and ICSB 545 showed 7 and 28% incidence, respectively, compared to 100% incidence in the susceptible checks (H 112 and 296B), and 11% in the resistant check, QL 3. All the 16 R-lines were highly susceptible (93-100% incidence).

**Anthraxnose resistance in sweet sorghum hybrid parent lines:** Twenty B-lines and 16 R-lines were evaluated for resistance to leaf anthracnose along with one variety (SSV 84) and a hybrid (NSSH 104), and resistant (A 2267-2) and susceptible (H 112) checks. The experiment was conducted in a completely randomized block design with 2 replications, 2 rows of 4 m length. The plants were whorl-inoculated with pathogen-infested sorghum grain 30 days after seedling emergence, and over-head sprinkler irrigation was provided for maintaining high humidity (>90%RH) required for disease development. Data on latent period (days from inoculation to symptom appearance on leaf lamina), and disease reaction (R = resistant- no infection or chlorotic flecks; MR = moderately resistant- brown spots without sporulation; and S = susceptible-lesions with sporulation), and disease severity (on 1 - 9 scale) were recorded on whole plant basis at soft dough stage. Of the 20 test B-lines, 11 lines (ICSB 279, ICSB 311, ICSB 453, ICSB 468, ICSB 479, ICSB 480, ICSB 487, ICSB 514, ICSB 545, ICSB 565 and ICSB 722) were resistant ( $\leq 3.0$  score) compared to 9.0 score on H 112. The latent period in the B-lines varied from 5.0 (ICSB 652) to 12.5 days (ICSB 453) compared to 5.0 days in H 112. Similarly, 5 R-lines (IS 23526, NSS 254, SSV 53, SPV 422 and ICSV 93046) were resistant ( $\leq 3.0$  score), and 7 lines (E 36-1, IS 21260, IS 2331, IS 23526, NSS 254, SP 4481-1, and SSV 53) exhibited MR disease reaction. The latent period among R-lines varied from 5.0 (SP 4511) to 8.5 days (SPV 422) compared to 5.0 days in a susceptible line, H 112 and 8.0 days in a resistant line, A 2267-2. Parent lines having resistance to downy mildew and anthracnose can be used to develop sweet sorghum hybrids having resistance to foliar diseases.

**Sweet sorghum population:** Sweet sorghum varieties and germplasm lines were planted along with SSV 74 F<sub>4</sub> and SSV 84 F<sub>4</sub> crosses bulks for introgression. However, due to earliness of F<sub>4</sub> bulk and late flowering of sweet sorghum varieties, introgression could not be carried out successfully. However, 57 steriles and 75 fertiles from SSV 74 F<sub>4</sub> bulk and 144 steriles and 137 fertiles from SSV 84 bulk were harvested. The introgression will be repeated for the development of sweet sorghum population.

**High tillering population:** Based on the tillerability and biomass, 18 steriles and 38 fertiles were harvested from the ICSP HT C<sub>11</sub> population bulk, 4 steriles and 15 fertiles with tillers were harvested from the SSV 74 F<sub>4</sub> bulk and 4 steriles and fertiles with tillers were harvested from the SSV 84 F<sub>4</sub> bulk. Steriles and fertiles will be mixed in a 3:1 ratio to constitute the C<sub>12</sub> population bulk, SSV 74 F<sub>5s</sub> bulk and SSV 84 F<sub>5s</sub> bulk. These will be advanced during 2007 poststrayn season.

We also evaluated 20 sweet stalk B-lines and 16 sweet stalk R-lines for downy mildew reaction in glasshouse using sandwich technique for anthracnose (artificial inoculation) and grain mold reactions during 2007 rainy season. Among the B-lines, ICSB 690, and ICSB 565 were resistant, and ICSB 545 moderately resistant to downy mildew; eight B-lines (ICSB 271, 453, 479, 480, 545, 690, 722 and ICSB 729) were resistant to grain mold, and 17 B-lines were moderately-resistant to anthracnose. Among the R-lines; three R-lines (NSS 254, SP 4482-1 and SP 4511-2) were resistant to grain mold; and seven R-lines (E 36-1, IS 21260, IS 2331, IS 23526, NSS 254, SP 4481-1 and SSV 53) were moderately resistant to anthracnose. No resistance was observed in R-

lines for downy mildew.

**Evaluation of segregating material for resistance to shoot fly, *Atherigona soccata* during the postrainy season:** During the post rainy season 2006/07, 205 F<sub>5</sub> lines along with the resistant, IS 18551 and susceptible, Swarna checks, were evaluated for shoot fly resistance in a randomized complete block design with three replications. Deadheart incidence ranged from 5.7 to 83.6%, and 76 lines suffered <30% deadheart incidence compared to 19.7% in the resistant check, IS 18551, and 83.6% in Swarna. In another trial, 166 F<sub>6</sub> lines were evaluated for shoot fly resistance along with IS 18551 and Swarna. Deadheart incidence varied from 17.9 to 91.6% in the test material. Nine lines suffered <25% deadhearts compared to 28.3% in the resistant check, IS 18551, and 83.8% in control Swarna.

In the F<sub>7</sub> trial, 19 lines were evaluated for shoot fly resistance along with resistant check IS 18551, and susceptible check Swarna. Deadheart incidence in the test material varied from 14.4 to 88.1%, and the lines 105-2, 104, 102, 107-3, 3183-1, 114-1 and 103 suffered <40% deadhearts compared to 37.2% in the resistant check, IS 18551, and 86.0% in Swarna.

RP Thakur, R Sharma and BVS Reddy

*MTP Output Target: 2007 6.1.2 SO: Major grain mold pathogens in sorghum growing states in India identified and their distribution in relation to weather factors characterized*

**Major grain mold pathogens:** A large number of fungi, both saprophytic and pathogenic have been reported to be associated with the sorghum grain mold complex. In order to find genetic resistance in sorghum lines it is important that fungi that are truly pathogenic and actively involved in host-pathogen interaction are identified and their relative frequency determined. Through an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002–2004 several pathogens consistently associated with grain mold were identified. The analysis of SGMVN data from these locations revealed that several species of *Fusarium*, *Curvularia lunata* and *Alternaria alternata* were generally more frequent and highly consistent than other fungi. Of more than 900 isolates of *Fusarium* obtained from grain samples from these locations, six species of *Fusarium* (*F. proliferatum*, *F. verticillioides*, *F. thapsinum*, *F. andiyazi*, *F. nygamai* and *F. sacchari*) were identified. Strains of some of these *Fusarium* species are known to produce fumonisins, a kind of mycotoxin that is hazardous to health.

**Influence of weather variables on occurrence of pathogenic mold fungi:** We studied the influence of weather variables, temperature (T) and relative humidity (RH), on the occurrence of major pathogenic fungi, such as *Fusarium* spp., *Curvularia lunata*, *Alternaria alternata* and *Phoma sorghina* associated with sorghum grain mold in India. The T and RH data, and frequency of mold fungi collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002–2004 was used for this study. Since minimum temperature (T<sub>min</sub>) and maximum temperature (T<sub>max</sub>) during flowering to physiological maturity are most critical for mold development, distribution of pathogenic fungi in relation to these weather variables was studied. It appears that T<sub>min</sub> 18–20°C and RH<sub>max</sub> around 80% favored *Curvularia* at Akola and Surat and higher RH<sub>max</sub> (around 90%) and almost same T<sub>min</sub> favored *Alternaria* and *Phoma* at Patancheru. However, high T<sub>min</sub> seems to favor *Fusarium* as the fungus was predominant at Parbhani having T<sub>min</sub> around 22°C.

RP Thakur and Rajan Sharma

Association of mycotoxin-producing *Fusarium* spp. with sorghum grain mold in field and/or in storage is important because mycotoxin-contaminated food and feed create health hazard for humans and cattle. Forty-seven cultures of *Fusarium* spp., obtained from molded sorghum panicles at ICRISAT were studied for their speciation and fumonisins (FB<sub>1</sub> & FB<sub>2</sub>) production potential. A preliminary morphological study at Medical Research Council, South Africa, revealed 17 of these cultures as potential fumonisin producers and subsequently 14 of these were confirmed through a mating type study at Kansas State University, USA. These cultures were tentatively identified into six different species: *F. proliferatum*, *F. thapsinum*, *F. verticillioides*, *F. sacchari*, *F. nygamai* and *F. andiyazi*. In a collaborative study with Iowa State University, Ames, 12 of these isolates were assayed for fumonisins FB<sub>1</sub> & FB<sub>2</sub> production using high performance liquid chromatography. Of these, *F. proliferatum* isolates produced higher FB<sub>1</sub> (2.318–7.560 µg/g) and FB<sub>2</sub> (0–8.478 µg/g) than other isolates. Insignificant amount of FB<sub>2</sub> was detected in isolates of *F. sacchari*, *F. andiyazi* and *F. nygamai* and in some isolates of *F. thapsinum*. FB<sub>1</sub> detected in potato dextrose-agar (PDA) culture of *F. proliferatum* was high (10.850 µg g<sup>-1</sup>) compared to that of *F. verticillioides* with no FB<sub>1</sub> detected. These results on species

identification and fumonisins production by *Fusarium* spp. involved in sorghum grain mold complex in India are an important addition to the available information on fumonisins production by *Fusarium* species. Based on colony growth characteristics on PDA, 682 cultures of *Fusarium* collected from five locations (Akola, Parbhani, Palem, Patancheru and Surat) in India were tentatively classified into six species with varying frequencies. The mean frequency of *F. proliferatum* across locations was 48%, followed by 33% for *F. thapsinum*, 9% for *F. verticillioides*, 5% for *F. andiyazi*, 2% for *F. sacchari* and 1% for *F. nygamai*. Both *F. sacchari* and *F. nygamai* were not detected in Parbhani and Patancheru isolates. Selected isolates from the above-mentioned 5 locations will be further analyzed through AFLP to identify toxigenic *Fusarium* spp. associated with grain mold in India.

RP Thakur and Rajan Sharma

**Contribution of host factors in mold resistance.** Several host morphological traits, such as panicle type, glume coverage, glume color, grain color and grain hardness are known to contribute to grain mold resistance in sorghum. We conducted a field trial consisting of 50 diverse sorghum lines including grain mold susceptible (SPV 104) and resistant (IS 8545) checks. The experiment was conducted. The sprinkler irrigation was provided twice a day for 30 min each on rain-free days from flowering to physiological maturity to provide high humidity (>90% RH) essential for mold development. The grain mold scores were recorded at physiological maturity using a 1 to 9 scale, where 1 = no mold infection (highly resistant) and 9 > 75% molded grains on a panicle (highly susceptible). Data on morphological traits were also recorded at physiological maturity. Five panicles from each test line were harvested to study the grain hardness. The mean grain mold scores ranged from 1.4 to 9.0 in the test lines. Data on morphological traits will be correlated with the average grain mold severity scores of 50 sorghum lines to determine the relative contribution of different morphological traits in grain mold resistance.

**Role of phenolics in grain mold resistance.** Resistance to grain mold is a complex trait and several biochemical traits have been shown to be associated with resistance. Phenolic compounds in sorghum caryopses are reported to improve resistance to insects, fungi and other pathogens and cultivars with high tannin content have been used as a source of mold resistance. We estimated Flavon-4-ols in seed samples of 6 susceptible (SGMR 3-3-5-6, PVK 801-4, IS 36469C 1187-1-2-9-8-2, SP 72521-2-6-6-6, SPV 104, Bulk Y) and 11 resistant (IS 12932-2, IS 13969-1, SGMR 24-5-1-2, SGMR 11-3-5-1, ICSB 377, IS 8219-1, SGMR 40-1-2-3, IS 41397-3, ICSB 402-3, ICSB 402-1-2, SPV 462-3) lines of sorghum to find out the likely association with mold resistance. Mean Flavon-4-ols values of grain mold resistant and susceptible sorghum lines were distinctly different from each other. More Flavon-4-ols got accumulated in the methanol and acidified methanol extracts of both molded as well as non-molded grains of resistant lines than in susceptible lines. Similarly, range of Flavon-4-ols extracted both in methanol as well as acidified methanol was very large in the resistant lines, whereas it was very narrow for the susceptible lines. More Flavon-4-ols were detected in the colored grains than in the white grains. In most of the lines, molded grains recorded more Flavon-4-ols than non-molded grains. Considerable increase in the Flavon-4-ols content in the methanol extract was also observed in the molded grains of a white-grain resistant line SPV 462-3. This indicates that expression levels of Flavon-4-ols in the biosynthetic pathway are enhanced in response to the pathogen attack. Therefore, concentration of Flavon-4-ols in the mature sorghum seed can give an indication about the expected reaction of the sorghum cultivars to grain mold and differential levels of Flavon-4-ols can be used as a biochemical marker for grain mold resistance. However, the results need further confirmation using susceptible and resistant lines following artificial inoculations under greenhouse conditions.

**Influence of weather variables on grain mold development.** We studied the influence of weather variables, temperature (T) and relative humidity (RH) on sorghum grain mold development. The T and RH data, and grain mold severity scores collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Resistance Stability Nursery (SGMRSN) conducted at four locations (Coimbatore, Dharwad, Parbhani and Patancheru) for two rainy seasons 2005 and 2006 were used for this study. The weekly averages (across locations and seasons) of T (Tmax and Tmin) and RH (RHmax and RHmin) for a 2-month post-flowering period (grain-filling to physiological maturity period) were correlated with the average grain mold severity scores of 32 sorghum lines of the SGMRSN. Positive and significant correlations ( $r = 0.96$ ,  $P < 0.05$ ) were found between average weekly Tmin (18.5 to 22.5°C) during the standard 37<sup>th</sup> and 38<sup>th</sup> week (the 1<sup>st</sup> and 2<sup>nd</sup> weeks after panicle emergence) and the average grain mold severity of sorghum lines. This two-week period coincided with the anthesis and ovary fertilization stages of most sorghum lines during which time infection by mold pathogens took place. Similarly, significant positive correlation was found between the average RHmax (76 to 96%) during the standard 41<sup>st</sup> and 42<sup>nd</sup> week (the 5<sup>th</sup> and 6<sup>th</sup> week after panicle emergence) and the average grain mold severity ( $r = 0.87$ ,  $P < 0.05$ ). This period, for most sorghum lines, coincided with hard-dough to physiological maturity stages, and during this period infected grains, under high humidity conditions, showed rapid colonization by various mold fungi. Such

infected grains developed growth of other saprophytic fungi as well when left in the field beyond physiological maturity. The regression analyses showed a near-linear relationship between Tmin and grain mold severity scores ( $R^2 = 0.96-0.99$ ), and between RHmax and grain mold severity scores ( $R^2 = 0.98-0.99$ ). Thus, the two most important weather variables, Tmin during anthesis to fertilization stage and RHmax during hard-dough to grain maturity stage appeared critical for infection and grain colonization by major mold pathogens (species of *Fusarium*, *Curvularia* and *Alternaria*) in the sorghum grain mold complex.

RP Thakur and Rajan Sharma

*MTP output target 2007 6.2.1 GN: 3 mapping populations between contrasting parents to identify QTLs for salinity tolerance and component traits of drought tolerance developed*

The phenotyping of one population developed to map QTLs for transpiration efficiency (TE) has been performed (ICGV86031 (high TE) x TAG24 (low TE)) in 2004 and 2005, and showed in both cases a good segregation pattern, with some transgressive segregation of a number of RILs reaching higher TE levels than the high TE parent ICGV86031. In this work now published (Krishnamurthy et al. 2007), we found that the surrogate traits of TE such as SLA, SCMR and  $^{13}\text{C}$  discrimination had poor relationship with TE measured gravimetrically. These results are very important because these surrogates have often been recommended and used for their convenience in assessing TE, with the assumption that they bear a good relationship with TE. Our results indicate therefore that care should be taken about using these surrogates as proxies for TE. The reason for the lack of relation is unclear, and it seems that the phenotypic contrast between the 2 parents for SLA and SCMR was limited. It may also be that other mechanisms are involved in the TE differences.

The lack of polymorphic markers for the parents of that population has hampered the progress towards the identification of markers for TE. Efforts have been made and about 140 markers, polymorphic between these two parents have been identified. This population will also be phenotyped in the field in 2007-08. Screening of parental genotypes with more than 900 SSR markers provided more than 120 polymorphic markers. Genotyping of the mapping population with all the polymorphic markers is in progress.

Vincent Vadez, L Krishnamurthy and Rajeev Varshney

*MTP output target 2007 6.2.2 GN: At least 10 genotypes with superior salinity tolerance identified*

Screening of 288 genotypes of groundnut, including the mini-core collection, was performed in 2005 rainy season in outdoor conditions, in which the overall VPD conditions were relatively low ( $1.17 \text{ g salt kg}^{-1}$  Alfisol). The evaluation was based on yield under saline and controlled conditions, and related parameters (pod number, biomass, etc.). The screening was repeated in 2006-07 postrainy season (November 06-April 07), in which the VPD was relatively high to measure G x E interaction for salinity tolerance, and to identify a set of contrasting genotypes for yield under saline conditions.

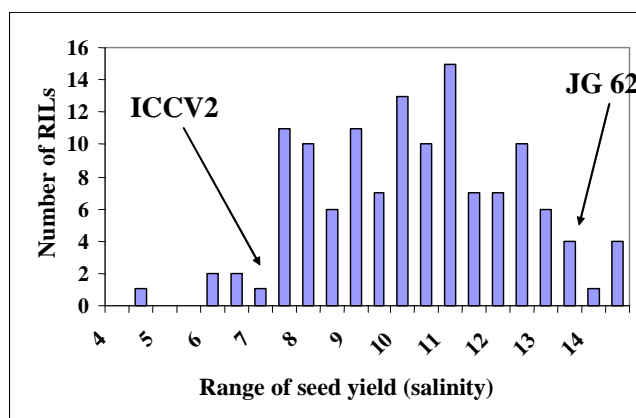
We observed large G x E interaction for salinity tolerance among the genotypes tested. This was expected as the light, temperature and humidity conditions under which the accessions were tested varied a lot. Yet, we were able to identify a set of 31 genotypes (15 tolerant and 16 sensitive) that showed a consistent response across environments. These genotypes were screened with 21 markers to assess their diversity at DNA level, and then to choose the most suitable parents for crossing. Out of these, 18 showed polymorphisms between the lines. Interestingly, we found that genotypes JL 24 (sensitive) contrasted with ICG (FDRS) 10 (tolerant) across seasons. A RIL population from these 2 parents is being developed for leaf diseases, and is now at  $F_5$  generation. Genotype CSMG 84-1 (sensitive) also contrasted with ICGS 44 and ICGS 76 (tolerant). RILs populations ICGS 44 x CSMG 84-1 and ICGS 76 x CSMG 84-1 have been developed for TE in the past years and are now at  $F_8$  stage. These populations can be used to phenotype for salt tolerance and to identify QTLs for salinity tolerance. There is no relationship between yield potential under control conditions and yield performance under saline conditions. Therefore, absolute yield data under saline conditions were used to assess salinity tolerance. We also observed a weak relationship between biomass at maturity and the pod yield at maturity, which indicated that, though biomass is low under saline conditions, the genotypic differences in biomass under saline conditions do not explain differences in pod dry weight. We also measured stem and leaf Na accumulation in 2006. We found no relationship between stem Na, leaf Na, and pod yield. These results are contrary to most of the literature on salinity tolerance, where shoot Na accumulation contributes to salt tolerance. These results are similar finding to those in chickpea. The data indicated that salt accumulation in the shoot is not responsible for the differences in tolerance.

V Vadez, R Aruna and L Krishnamurthy

*MTP output target 2007 6.2.1 CP: Phenotyping of ICCV 2 x JG 62 mapping population for salinity tolerance completed and data analyzed with available markers data for QTL mapping*

Data on root traits on two RIL populations (ICC 4958 x ICC 1882 and ICC 283 x ICC 8261) has been collected. A total of 124 markers polymorphic in mapping population ICC 4958 x ICC 1882 and 150 markers in ICC 283 X ICC 8261 have been found. The genotyping of the ICC 4958 x ICC 1882 population with corresponding polymorphic markers is still in progress. The genotyping is taking a longer time than initially anticipated as there are now a larger number of SSR markers available. Genotyping with the remaining markers and statistical analysis of the data for identification of additional markers for root QTLs would be completed in 2008.

The population developed between JG 62 and ICCV 2, tolerant and sensitive to salinity stress, respectively, (over two years of screening) was phenotyped for two consecutive years (2005-06 and 2006-07). There was a good agreement between the seed yield data obtained across two years ( $r^2 = 0.47$ ). The segregation pattern was also good, with JG 62 and ICCV 2 being on the extreme of the ranking of genotypes (Fig. 6).



**Figure 6: Segregation for seed yield under salinity in chickpea cross ICCV 2 x JG 62.**

In previous screening for salinity tolerance, we had found evidence that the time to flowering is related to the level of salinity tolerance, under short growing season length that is prevalent at ICRISAT-Patancheru. Therefore, part of the differences in tolerance between ICCV 2 and JG 62 is explained by 17 days difference in their time to flowering under saline conditions. When the frequency distribution for seed yield under saline conditions was made, it was clearly evident that discrimination occurred for time to flowering. Therefore, seed yield data need to be analyzed by considering two groups of genotypes separately, so as to separate the effects of phenology on salt stress tolerance from salinity tolerance *per se*. We also tested the hypothesis that the decrease in seed yield in the RIL was due to a decrease in seed number, rather than to a decrease in the 100-seed weight (which would measure seed filling), following the hypothesis that were made in 2007 using germplasm accessions. RILs that appeared to be tolerant maintained a larger relative seed number, whereas differences in seed filling did not explain the differences in seed yield.

This RIL population will again be phenotyped in 2007-08. To decrease the effect of earliness and expand a little the vegetative phase of early segregants, sowing was performed a little later (November), and a slightly higher salt treatment (125 mM) was used because the effect of 100 mM NaCl had induced a moderate reduction in seed yield. Marker data for this population is also available and QTL mapping should start once we have the third set of phenotyping data.

V Vadez, L Krishnamurthy and PM Gaur

*MTP output target 2007 6.3.1 FORT: 75 transgenic events of groundnut with maize psy1 gene developed and screened for high  $\beta$ -carotene production in the contained greenhouse*

*Agrobacterium*-mediated genetic transformation of groundnut was carried out using binary construct pCAMBIA 2300:Oleo-PSY1 for  $\beta$ -carotene enhancement in groundnut seeds. Ninety primary  $T_0$  groundnut transgenic plants containing the maize phytoene synthase (*zmpsy1*) gene were established in the containment greenhouse for seed development and characterization. Molecular analysis of the primary ( $T_0$ ) transgenic events using PCR



with gene-specific primers revealed the integration and presence of the *zmpsy1* in 75 out of the 90 events. Southern hybridization analysis using the gene-specific probes confirmed the integration of transgene in 20 out of 25 selected events. Transgene expression in the developing pods of groundnut was observed by RT-PCR analysis. The presence of mRNA transcripts of *zmpsy1* gene was observed in the selected plants. Seeds of T<sub>1</sub> generation of the transgenics were collected from 80 events and 70 events were advanced to T<sub>1</sub> generation in the containment greenhouse.

For the development of antibiotic marker-free groundnut transgenics, *zmpsy1* gene driven by the oleosin promoter was sub-cloned into the binary vector pPZP200 and mobilized into *Agrobacterium* strain C58. About 30 marker-free primary (T<sub>0</sub>) transgenic events of groundnut transformed with the binary construct 2300: *nptII* (minus *nptII* gene) were established in the containment greenhouse. Molecular analysis of the T<sub>0</sub> transgenic plants using PCR with gene specific primers (both *zmpsy1* junction and *nptII* primers) revealed the presence of only *psy1* gene in 23 out of 30 events. This showed an effective frequency of about 70% in the recovery of transgenic plants using marker-free system. Development of more marker-free transgenic events is in progress. For development of antibodies against phytoene synthase, the *zmpsy1* gene was cloned into pET expression vector. The over expression of PSY1 protein in *E. Coli* is being analyzed prior to its purification for the development of antibodies.

KK Sharma

*MTP output target 2007 6.3.2: 50 transgenic events of pigeonpea with maize psy1 gene developed and screened for high β-carotene production in the contained greenhouse*

*Agrobacterium*-mediated genetic transformation was carried out using binary construct pCAMBIA 2300:Oelo-PSY1 for β-carotene enhancement in pigeonpea seeds. Over 140 primary T<sub>0</sub> pigeonpea transgenic events were established in the containment greenhouse for seed development and characterization. Molecular analysis on primary pigeonpea transformants (T<sub>0</sub> plants) using PCR with gene specific primers (both *zmpsy1* junction and *nptII* primers) revealed the integration and presence of the *zmpsy1* gene in 85 out of 142 events. Southern analysis using gene specific probes are being performed for confirmation of transgene in these events. RT-PCR analysis of the developing pods of pigeonpea is being carried out to observe the transgene expression in these events. Seeds of T<sub>1</sub> generation of pigeonpea transgenics were collected from 130 events to study the transgene inheritance, segregation and expression in the progeny.

**Development of pigeonpea transgenic events for enhanced level of methionine:** For overproduction of methionine in pigeonpea seeds, *Agrobacterium*-mediated genetic transformation of pigeonpea was carried out using the binary construct pHS723:SSA containing sunflower seed albumin gene (*ssa*) driven by the vicillin promoter for seed-specific expression. Thirty-eight primary T<sub>0</sub> pigeonpea transgenic plants containing *ssa* gene were established in the containment greenhouse for seed development and characterization. Molecular analysis of primary pigeonpea transformants (T<sub>0</sub> plants) using PCR with gene specific primers (both *ssa* and *nptII* primers) revealed the integration and the presence of *ssa* gene in 32 out of 38 events. Southern analysis using gene specific probes is being performed for confirmation of transgene in these events. RT-PCR analysis of developing pods of pigeonpea is being carried out to observe transgene expression in these events. Seeds of T<sub>1</sub> generation of pigeonpea transgenics were collected from 30 events carrying *ssa* gene to study transgene inheritance, segregation and expression in these events.

KK Sharma

*MTP output target 2007 6.3.1 DTOX: Enzyme-linked immunosorbent assay (ELISA) assay developed for the estimation of aflatoxin adducts in human serum*

Aflatoxin is produced as a secondary metabolite of the fungus *Aspergillus flavus*. Consumption of aflatoxin contaminated food forms the aflatoxin-lysine adducts in human blood and leads to liver damage. Frequent exposure to aflatoxin increases the risk of liver cancer. Since aflatoxin-lysine adduct in blood can be detected upto 20- 30 days, detection of aflatoxin –lysine adduct in blood serves as a biomarker. Several physico-chemical methods are available for detection, however, we have developed ELISA based technology for detection of aflatoxin in human blood. This method was used to analyze blood samples from people affected with liver related diseases. About 80 blood samples were collected from the Asian Institute of Gastroenterology, Hyderabad (India) along with samples information on their food habit and clinical status. Patients were selected based on clinical diagnosis and were grouped as: patients with liver cirrhosis, chronic liver disease, hepatitis B, hepatitis C, alcoholic liver disease, non alcoholic liver disease, liver cirrhosis with hepatitis B, liver cirrhosis with hepatitis C, hepatocellular carcinoma, chronic liver disease with hepatitis B/ hepatitis C. Their food habits

including people eating more peanut, maize, rice, chilies, source of food, their socio-economic status were surveyed. The blood samples were collected and serum was separated and brought to ICRISAT-Patancheru in dry ice.

To extract aflatoxin from the blood samples, first the albumin was separated from serum of the blood samples and digested with the protease-K enzyme, followed by ELISA. Among 80 samples, 50% of the samples were free from the toxin and the remaining samples were positive for aflatoxin with the range 6 - 212 pg mg<sup>-1</sup> of the albumin. Among the aflatoxin positive samples, 45 were from patients having either hepatitis B or hepatitis C, and/or with liver disease. The result indicated there is a high risk for liver cancer when hepatitis B combines with aflatoxin. In another study, we collected 165 blood samples randomly, and ELISA result indicated that there was no aflatoxin positive among these people, and all of them were free from the aflatoxin adduct. This study provides the scope for preventive interventions in persons at high risk of liver cancer. A publication on detection methodology and the data obtained from different groups of liver diseases patients is being prepared.

F Waliyar and P Lava Kumar

## **Project 6 Research Highlights 2007**

### **Groundnut**

*ICGV 04087 produced significantly higher pod yield (6.8 t ha<sup>-1</sup>) than the highest yielding control ICGV 98373 (5.4 t ha<sup>-1</sup>) in the Elite Virginia Trial, while in the ICGV 05099 produced significantly higher pod yield (6.6 t ha<sup>-1</sup>) than the best performing control ICGV 86590 (5.1 t ha<sup>-1</sup>) in the Advanced Spanish Trial at ICRISAT-Patancheru.*

*Stem necrosis disease caused by Tobacco Streak Virus (TSV) has emerged as a serious threat to groundnut cultivation in India. Of the 56 wild Arachis spp. germplasm accessions from 20 evaluated for resistance to TSV, 8 accessions belonging to Arachis duranensis; and one each to A. villosa and A. stenosperma showed high levels of resistance to TSV.*

*Thirteen transgenic groundnut plants (31B, 47F, 48A, 48D, 48E, 48F, 1-1, 1-4, 4-6, 9-2, 9-3, 9-4 and 30-6) were free from systemic symptoms to TSV, as confirmed by DAC ELISA. Of the 24 transgenic groundnut events tested for peanut bud necrosis disease, event numbers 3, 4, 7, and 11 showed lower disease (20%) incidence compared to the control, JL 24 (90%).*

*Both additive and dominance gene action were significant for late leaf spot disease resistance in groundnut. Gene action for a number of lesions was governed by additive gene action in ICG 11337 x JL 24, and non-allelic additive x dominance gene action in ICG 13919 x JL 24.*

*A lysimetric system has been designed to evaluate groundnut and chickpea genotypes for drought tolerance using large PVC cylinders (20 cm in diameter and 1.2 m long). There was no relationship between stem Na, leaf Na, and pod yield under saline conditions. These results are contrary to most of the literature on salinity tolerance, where shoot Na accumulation contributes to salt tolerance.*

*ICGV 00348 - a drought tolerant variety, has been identified for its release in zone V in India; while ICGV 00440 - a confectionery foliar disease resistant variety, has been proposed for release as Namnamma 2 in the Philippines.*

### **Chickpea**

*Eleven chickpea varieties (ICCVs 04512, 04513, 05525, 05526, 05527, 05528, 05529, 05530, 05531, 05532, and 05533) with resistance to Fusarium wilt, Aschochyta blight, and Botrytis gray mold have been developed. Nine chickpea genotypes (JG 62, C 104, L 550, K850, Chafa, Annigeri, CPS 1, JG 74, BG 212, WR 315 and ICC 506) differed significantly in their reaction to different isolates of F. oxysporum f.sp. ciceris, and were selected for use as differentials to monitor races of the pathogen.*

*The wild relatives of chickpea have shown very high levels of antibiosis to pod borer, Helicoverpa armigera (2.4 to 8.6 mg larval weight on the wild species accessions: PI 353625, PI 532928, PI 599080, PI 599082, PI 599083, PI 899089 and PI 593719 compared to 32.2 mg on the wild local, C. microphyllum).*

Segregation pattern in the population derived from JG 62 x ICCV 2 for root traits was good, with JG 62 and ICCV 2 being on the extremes. The parental lines were screened with 513 SSR markers, of which 101 SSR markers were polymorphic.

Several transgenic chickpea events carrying the DREB1A transcription factors driven by a stress-responsive promoter rd29A showed significant increase in transpiration efficiency compared to the wild type.

### **Pigeonpea**

Four pigeonpea lines (ICPL 20116, ICPL 20127, ICPL 20136 and ICPL 20138) were found to be asymptomatic to both Fusarium wilt and sterility mosaic virus. The pigeonpea lines ICPL 332 WR, ENT 11 and ICP 7035 have been tested on farmers' fields to assess their usefulness in pest management under farmers' field conditions. Interspecific derivatives Pant A-2 x *C. albicans* - 9-2-1, Pant A-2 x *C. lanceolatus* - 1-2, Prabhat x *C. scarabaeoides* -3-2-2-1, and Prabhat x *C. scarabaeoides* - 12-2-2 showed moderate levels of resistance to pod borer, and had grain yield potential comparable to ICPL 332.

### **Sorghum**

Significant progress has been made in identifying sweet sorghum cultivars for ethanol production. Four single-plant BC3-derived selections homozygous for the SBI-10 QTL had 82% deadhearts, and showed leaf glossiness score of 3.6 compared to 93% deadhearts and glossiness score of 5.0 for the shoot fly susceptible recurrent parent, BTx623. SBI-05 glossiness QTL from IS 18551 may not contribute substantially to shoot fly resistance, and thus need not be a target for marker-assisted selection.

### **Bio-fortification, bio-detoxification, and safer practices for pest management**

Eighteen groundnut transgenic events with resistance to *Aspergillus flavus* showed higher chitinase activity than the untransformed control.

Polyclonal and monoclonal antibodies for the detection of total aflatoxins, aflatoxin B1 and M1 have been developed.

Seven Actinomycetes and 17 bacteria have been identified that inhibited *A. flavus* growth under plate culture conditions.

Approximately 200 researchers from NARS, and 1000 farmers in India and Nepal, were trained in NPV production. ELISA protocol for the diagnosis and quality control of NPVs of *Helicoverpa armigera*, *Spodoptera litura*, and *Amsacta albistriga* has been developed.

*Bacillus subtilis* (BCB19) and SB19 (probably *B. mycoides*) performed at par with commercially available Bt formulation and/or synthetic pesticides in managing *Helicoverpa podborer*.

The sex ratio of the *Helicoverpa armigera* parasitoid, *Camponotus chlorideae* was male biased at 12°C and female biased at 27°C. There were no significant differences in parasitism of *H. armigera* eggs and larvae between Bt-transgenic and non-transgenic cottons.

## **Research Results**

**Output A: Improved germplasm and varieties of sorghum, finger millet, pigeonpea, chickpea and groundnut with pro-poor traits and associated advanced knowledge of selection tools and breeding methods made available to partners internationally**

### **Groundnut**

Internal output target GN 6A.1: Each year 50-60 diverse trait-specific (resistance to rust, late leaf spot (LLS), and other emerging diseases and pests, short- and medium-duration, dual-purpose (food and fodder), oil types and confectionery types), high yielding breeding populations and advanced breeding lines developed

**Activity GN 6A.1.1: Evaluate and introgress new germplasm sources (cultivated and wild *Arachis* species) of variability for yield components, resistance to rust, LLS, and other emerging diseases, crop duration, and food and fodder quality traits**

*Milestone: At least 100 crosses involving diverse germplasm and breeding lines for aforementioned traits effected (SNN/RA/FW) Annual*

**Evaluate and introgress new germplasm sources for resistance to biotic stresses and quality traits:** Eighty-one crosses (27 for short-duration, 23 for medium-duration with high oil content, 21 for confectionery, and 10 for foliar disease resistance) were made in 2006/07 postrainy and 2007 rainy seasons to generate populations for selection for high yield, disease resistance, and desired crop-duration and confectionery traits in desirable agronomic backgrounds. New parents used in hybridization included high yielding foliar diseases resistant lines ICGV nos. 04060, 04078, 04093, 04091, LC BG 2 and LC BG 4. In the medium-duration and high oil content crosses, high yielding lines were ICGV nos. 01274, 04124, 04149, 05063, 94434, 06122, 00017, Somnath and ICGV 06085. New parents used for producing confectionery material were ICGV nos. 05176, 05198, 06189, 05170, 05182 and 05198. For short-duration, the high yielding breeding lines used were ICGV nos. 93437, 00350, 91114, 00308, 99195 and 91123. In addition to advanced breeding lines, DH 86 and K 134 were also used in the short-duration breeding program.

SN Nigam and R Aruna

**Evaluation of advanced breeding lines for resistance to LLS and rust:** Five replicated yield trials, namely: 1) elite foliar diseases resistant groundnut variety trial- erect bunch (Spanish var. vulgaris and Valencia var. fastigiata) - EFDRGVT SB; 2) elite foliar diseases resistant groundnut variety spreading bunch (Virginia var. hypogaea) - EFDRGVT VB; 3) advanced foliar diseases resistant groundnut variety trial – (Spanish bunch) - AFDRGVT SB; 4) advanced foliar diseases resistant groundnut variety trial (Virginia bunch) AFDRGVT VB; and, 5) foliar diseases resistance trial (Virginia and Spanish bunch) FDRVB/SB; comprising 110 advanced breeding lines were screened for resistance to LLS and rust. Experiments were laid out in a broad-bed-and-furrow (BBF) system with two replications. The size of each plot was 1.5 m x 4 m, with inter-row spacing of 30 cm, and 10 cm between plants. At 53 days after sowing (DAS), plots were inoculated with LLS and rust by spraying the infected and test rows with a mixed conidial suspension of *Phaesariopsis personata* conidia and *Puccinia arachidis* urediniospores. Subsequent to inoculation, perfo-irrigation was provided daily for 30 minutes in the evening for 30 days for optimum disease development. Disease symptoms for LLS and rust were rated on a 1 - 9 disease severity scale at 74, 89 and 104 DAS.

Development of LLS and rust was uniform within the infector rows (100% infection in susceptible controls). Highly significant differences ( $P \leq 0.001$ ) were observed amongst genotypes in all trials for LLS disease severity. Similar results were observed for rust, except in AFDRGVT VB and EFDRGVT VB trials. In all trials, the coefficient of variation (CV%) was 4.7 to 7.9% for LLS, and 10.9 to 21.2% for rust, indicating consistency of the test for resistance to foliar diseases. Of the 110 breeding lines tested, none of the test lines was rated as resistant (disease severity rating of <3) to LLS at 104 DAS. However, 48 lines had a disease severity score of 4–6 (moderately resistant), while 62 lines were classified as susceptible (severity rating of 7–9). Half of the 48 lines classified as moderately resistant to LLS were Spanish bunch types (Table 1). With regard to rust, 101 lines showed good resistance (score 1–3), 7 lines were classified as moderately resistant, and two lines were susceptible at 104 days after sowing (Table 1).

**Table 1. Evaluation of advanced breeding lines for LLS and rust resistance (ICRISAT, Patancheru, 2007 rainy season).**

| Trial          | No. of lines tested | Disease rating to |      |      |      |      |      |
|----------------|---------------------|-------------------|------|------|------|------|------|
|                |                     | LLS               |      |      | Rust |      |      |
|                |                     | 1-3*              | 4-6* | 7-9* | 1-3* | 4-6* | 7-9* |
| EFDRGVT (SB)   | 16                  | Nil               | 6    | 10   | 13   | 3    | Nil  |
| EFDRGVT (VB)   | 10                  | Nil               | 3    | 7    | 10   | Nil  | Nil  |
| AFDRGVT (SB)   | 32                  | Nil               | 20   | 12   | 31   | Nil  | 1    |
| AFDRGVT (VB)   | 36                  | Nil               | 11   | 25   | 35   | 1    | Nil  |
| FDRGVT (SB/VB) | 16                  | Nil               | 8    | 8    | 12   | 3    | 1    |

|              |            |            |           |           |            |          |          |
|--------------|------------|------------|-----------|-----------|------------|----------|----------|
| <b>Total</b> | <b>110</b> | <b>Nil</b> | <b>48</b> | <b>62</b> | <b>101</b> | <b>7</b> | <b>2</b> |
|--------------|------------|------------|-----------|-----------|------------|----------|----------|

\*Disease severity score on 1 – 9 scale: 1 – 3 = resistant; 4 – 6 = moderately resistant; 7 – 9 = susceptible.

**Performance of F<sub>2</sub>s, F<sub>4</sub>s and F<sub>8</sub>s populations for resistance to LLS and rust under field conditions:** Six populations (258 lines) were evaluated for resistance to LLS under field conditions during the 2007 rainy season in un-replicated 9 m row plots, with 60 cm inter-row spacing, and 10 cm between the plants. TMV 2, a cultivar highly susceptible to LLS, was planted between every five-test rows to facilitate disease spread. At 53 DAS, plots were inoculated by spraying a mixed suspension of *P. personata* conidia and *P. arachidis* urediniospores in the evening. Twenty-four hours after inoculation, moisture was provided by perfo-irrigation for 30 minutes for 30 days to encourage disease development. All populations were evaluated on a 1 - 9 rating scale for foliar diseases resistance at harvest. The development of both diseases in the field was uniform in the infector rows and the experimental plots, indicating good inoculum distribution. Breeding populations were categorized as resistant (scores of 1 - 4), moderately resistant (scores of 5 - 7) or susceptible (scores of 8 - 9). A few single plants from the F<sub>4</sub> generation, (IGX-050166-F2SSD-SSD) derived from ICGV 01328 x ICGV 95469 and the F<sub>6</sub> generation (ICGX-040108-F2-SSD-B1-B1-B2) derived from ICG 13917 x ICG 10889 showed resistance to LLS (scores 1 - 4). A total of 65 progenies from six breeding populations (F<sub>2</sub> and F<sub>4</sub> - F<sub>8</sub>) showed moderate levels of resistance.

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*Milestone: 15-20 new high yielding lines with resistance to aforementioned biotic stresses and quality and adaptation traits identified and made available to NARS (SNN/RA/FW) Annual*

**Foliar diseases resistance:** The trait-specific international trials were made available, on request, to NARS collaborators. The promising advanced lines from on-station elite trials are distributed every two years. During the 2006/07 postrainy season, 177 F<sub>2</sub>-F<sub>7</sub> bulks and 77 single plants were sown for evaluation. From these, 272 F<sub>2</sub>-F<sub>7</sub> bulks were selected, and 14 bulks were included in the replicated yield trials. Promising selections came from ICG 13917 x ICG 10903 and ICG 13917 x ICG 10889. During the 2007 rainy season, 258 F<sub>2</sub>-F<sub>8</sub> bulks were sown for evaluation. From these, 209 F<sub>2</sub>-F<sub>8</sub> bulks and 114 single plants were selected. The most promising selections (13) came from (ICGX 040017 x ICG 11337), (ICGX 040018 x ICG 11325), (ICGX 040108 x ICG 10889), (ICGX 040111 x ICG 000036), (ICGX 040113 x ICG 000036) and (ICGX 040120 x ICGV 94118). In another trial, we evaluated 120 advanced breeding lines (including controls) in 6 replicated trials, and 134 advanced breeding lines in 2 augmented trials in the 2006/07 postrainy season for pod yield. During the 2007 rainy season, 110 advanced breeding lines (including controls) in 5 replicated trials were evaluated both for disease resistance and yield. Analysis of trial data for 2007 rainy season is in progress.

During 2006/07 postrainy season, in an Elite Trial (Spanish), ICGV 04068 produced significantly higher pod yield (6.3 t ha<sup>-1</sup> with 85% shelling outturn, rust score<sup>\*\*</sup> = 2.5, LLS score<sup>\*\*</sup> = 5.0) than the highest yielding control ICGV 98374 (4.5 ± 0.54 t ha<sup>-1</sup>, rust = 2.0, LLS = 7.5). In Elite Trial (Virginia), ICGV 04087 produced significantly higher pod yield (6.8 t ha<sup>-1</sup> with 69% shelling outturn, 2.0, 4.5) than the highest yielding control ICGV 98373 (5.4 ± 0.23 t ha<sup>-1</sup>, 2.0, 7.0). In an Advanced Trial (Spanish), ICGV 05099 produced significantly higher pod yield (6.6 t ha<sup>-1</sup>; 72%; 2.0; 5.0) than the best performing control ICGV 86590 (5.1 ± 0.63 t ha<sup>-1</sup>, 2.0, 7.0). In an Advanced Trial (Virginia), three varieties ICGV 05137, 05141 and 05112 produced significantly higher pod yield than the highest yielding control ICGS 76 (5.1 ± 0.30 t ha<sup>-1</sup>, 3.0, 7.0). ICGV 05137 produced highest pod yield (5.9 t ha<sup>-1</sup>; 71%; 2.0, 5.0). In the preliminary trial (Virginia), three varieties ICGV nos. 06175, 06161 and 06168 significantly outyielded the highest yielding control ICGS 76 (5.0 ± 0.65 t ha<sup>-1</sup>, 3.5, 7.0). ICGV 06175 produced highest pod yield (5.8 t ha<sup>-1</sup>; 73%; 2.0, 5.0). Six Spanish and three Virginia entries were selected for future international trials. (\*\* Rust and LLS score taken from the 2006 rainy season trials).

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**High oil content:** Forty-six breeding lines along with three controls were evaluated over seven seasons (3 postrainy and 4 rainy seasons) to select lines for High Oil International Varietal Trials. There was a significant genotype x environment interaction. The top five genotypes with high oil content were ICGV 00351 (oil 53.1 % and protein 21.1%), ICGV 01279 (oil 53 % and protein 22.6%), ICGV 00017 (oil 52.9 % and protein 20.6%), ICGV 00171 (oil 51.7 % and protein 22.6%), and ICGV 01249 (oil 51.7 % and protein 22.7%). Twenty five new advanced breeding lines were selected for evaluation in the high oil trial during the 2007/08 postrainy season.

**Medium-duration:** During the 2006/07 postrainy season, 202 F<sub>2</sub>- F<sub>7</sub> bulks and 40 single plants were evaluated, out of which 198 F<sub>2</sub>- F<sub>7</sub> bulks and 54 single plants were selected for further evaluation. Out of the 198 bulk, 48

were included in replicated yield trials. The most promising 5 selections came from crosses (ICGV 98293 x ICGV 00308), (ICGV 01279 x ICGV 92206), and (ICGV 95469 x ICGX 000038). In 2007 rainy season, 150 selections were sown for evaluation. From these, 90 F<sub>2</sub> – F<sub>7</sub> bulks and 51 single plant selections were made. The most promising selections (15) came from (ICGV 99212 x sunoleic 95R) x ICGV 90196), (ICGX 020032 x ICGV 01271), and (TAG 24 x ICG 13919). In another trial, we evaluated 257 advanced breeding lines (including controls) in 8 replicated trials and 188 advanced breeding lines in 2 augmented trials in the 2006/07 postrainy season. During 2007 rainy season, we evaluated 193 advanced breeding lines (including controls) in 6 replicated trials. The trial data for 2007 rainy season is yet to be analyzed.

In the Elite Trial (Spanish), 3 lines ( $6.9-6.8 \pm 0.45 \text{ t ha}^{-1}$ ) significantly out-yielded the best control ICGV 95070 ( $5.2 \text{ t ha}^{-1}$  pod yield; 80% shelling outturn; 61.0 g 100-seed weight; 54% oil content;  $2.3 \text{ t ha}^{-1}$  oil yield). The best entry in the trial was ICGV 04115 ( $6.9 \text{ t ha}^{-1}$ , 78%, 50.5 g, 53%,  $2.9 \text{ t ha}^{-1}$ ). In the Elite Trial (Virginia), ICGV 04149 produced significantly higher pod yield ( $5.9 \pm 0.44 \text{ t ha}^{-1}$ , 80%, 51.8 g, 49.6%,  $2.3 \text{ t ha}^{-1}$ ) than the best control ICGS 76 ( $4.9 \text{ t ha}^{-1}$ , 80%, 63.7 g, 48.0%,  $1.9 \text{ t ha}^{-1}$ ). In Advanced Trial (Virginia), ICGV 06020 produced significantly higher pod yield ( $5.5 \pm 0.55 \text{ t ha}^{-1}$ , 71%, 50.4 g, 51.7%,  $2.0 \text{ t ha}^{-1}$ ) than the best control C 198 ( $4.2 \text{ t ha}^{-1}$ , 73%, 64.4 g, 49.4%,  $1.5 \text{ t ha}^{-1}$ ). Seven Spanish and four Virginia entries were selected for international trials.

**Confectionery type:** During the 2006/07 postrainy season, 93 F<sub>2</sub>-F<sub>6</sub> bulks were sown for evaluation. From these, 44 F<sub>2</sub>-F<sub>6</sub> bulks and 438 single plants were selected for further evaluation. The most promising selections with high pod yield and large pod size came from crosses ICGX-950067 x ICGX-950065, and ICGV00391 x ICGV 00440. During the 2007 rainy season, 482 selections were planted for evaluation. From these 312 F<sub>2</sub>-F<sub>7</sub> bulks and 85 single plants were selected. The most promising selections (7) came from ICGX 010073 x ICG 6670, ICGX 010073 x ICGX 010077, ICGX 960238 x ICGV 02242, ICGX 010073 x ICGV 02242, ICGX 00440 x ICGX 960065, and ICGX 00456 x ICGX 960067.

We also evaluated 105 advanced breeding lines (including controls) in 6 replicated trials and 40 advanced breeding lines in an augmented trial in the 2006/07 postrainy season. During the 2007 rainy season, 70 advanced breeding lines (including controls) were evaluated in 5 replicated trials in the 2007 rainy season. Analysis of trial data for 2007 rainy season is in progress. During the 2006/07 postrainy season, in the Preliminary Trial (Spanish), ICGV 06212 produced significantly higher pod yield ( $7.2 \pm 0.56 \text{ t ha}^{-1}$ , 57% shelling, 85.0 g 100 seed weight) than the best control ICGV 97045 ( $5.7 \text{ t ha}^{-1}$ , 53%, 107.0 g).

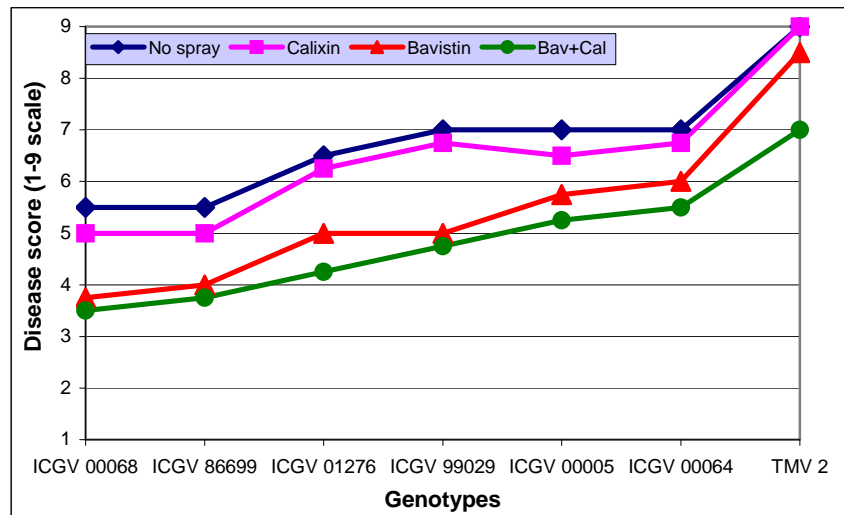
**Short-duration:** We evaluated 107 F<sub>2</sub>-F<sub>7</sub> bulks and 35 single plants during the 2006/07 postrainy season. From these, 51 F<sub>2</sub>-F<sub>7</sub> bulks and 171 single plants were selected. The most promising selections came from ICGV 99219 x ICGV 94361. During the 2007 rainy season, 226 selections were sown for further evaluation. From these, 101 F<sub>2</sub>-F<sub>8</sub> bulks and 313 single plants were selected. The most promising selections (3) came from ICGV 98294 x ICG 3540, ICGV 01279 X ICGV 92206 and ICGV 00296 X ICGV 98003. We also evaluated 179 advanced breeding lines (including controls) in 5 replicated trials in the 2006/07 postrainy season, while during the 2007 rainy season, 98 advanced breeding lines (including controls) in 3 replicated trials were evaluated. The trial data is yet to be analyzed. During the 2006/07 postrainy season, none of the new breeding lines outyielded the best control in all the four trials. In another trial, 45 elite entries, originating from different International Short-duration Groundnut Varietal Trial (ISGVT) over the past 10 years, were evaluated with 5 controls in a 7 x 7 lattice design. Five entries outyielded ( $2.4-2.0 \pm 0.20 \text{ t ha}^{-1}$ ) the highest yielding early-maturing control ICGV 89104 ( $1.6 \text{ t ha}^{-1}$  pod yield, 63% shelling outturn, 38 g 100 seed weight). ICGV 95290 ( $2.4 \text{ t ha}^{-1}$ , 67% and 51 g), ICGV 00338 ( $2.3 \text{ t ha}^{-1}$ , 65% and 46 g), and ICGV 00298 ( $2.1 \text{ t ha}^{-1}$ , 61% and 37 g) were the most promising entries in the trial. Twelve (Spanish) entries were selected and included in new International Trial (IX Series).

SN Nigam and R Aruna

**Evaluation of groundnut lines resistant to LLS and rust during rainy 2007 under field conditions:** Late leaf spot (LLS) (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*) are the most important fungal disease constraints to groundnut production in India, particularly during the rainy season (June–October). Systematic screening of groundnut germplasm and breeding lines was initiated in the field at ICRISAT, Patancheru, India, with a view to incorporate LLS and rust resistance in to high yielding cultivars with farmer preferred agronomic and quality characters suited to different environments. Five groundnut breeding lines; ICGV 00005, ICGV 00064, ICGV 01276, ICGV 99029, and ICGV 00068 along with one susceptible (TMV-2) and resistant (ICG 86699) control cultivars were evaluated against LLS and rust.

The experiments were laid out in a broad-bed-and-furrow (BBF) system with inter-row spacing of 30 and 10 cm between plants in a randomized complete block design (RCBD) with three replicates. At 53 days after sowing the plots were inoculated with LLS and rust by spraying infector and test rows with conidial suspension of *P. personata* conidia and *P. arachidis* uredinio spores, respectively. Subsequently, perfo-irrigation was given daily for 15 minutes in the evening hours for 30 days to maintain high humidity required for disease development. Additionally, for LLS trials, plots were sprayed with Calixin to control rust ( $0.5 \text{ ml L}^{-1}$ ) at regular intervals, whereas the plots meant for assessing resistance to rust were sprayed with Bavistin to control LLS ( $3 \text{ g L}^{-1}$ ). In another treatment, both LLS and rust were controlled using Bavistin and Calixin. LLS and rust were scored at 74, 89 and 104 days after sowing based on a 1 - 9 disease severity rating scale.

Results of the trial are presented in Figure 1. In comparison to the control treatment, LLS severity was significantly lower in plots sprayed with both Bavistin and Calixin with scores ranging from 1.5 to 2.3 (Fig. 1). As expected, all genotypes performed equally well in these plots, where both diseases were controlled. Nonetheless, in all treatments, ICGV 00068 had the lowest LLS disease severity scores, followed by ICGV 86699, and ICGV 01276. Rust disease severity was low, with an average score of 2.0 (data not shown), in contrast to the susceptible cultivar (TMV 2), which had a mean disease severity score of 8.0. This suggests that the breeding lines possess good level of resistance to rust at 104 days after sowing, and these will be useful in future breeding programs.



**Figure 1. Reaction of four genotypes to late leaf spot disease at 104 days after sowing at ICRISAT, Patancheru, 2007 rainy season.**

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*Milestone: 50 lines of advanced generation interspecific derivatives of groundnut evaluated for LLS disease and promising lines identified (FW/NM/PLK) 2008*

*Milestone: Field trials of five stable, promising interspecific derivatives conducted in target location for LLS resistance and yield (NM/FW/SNN/RA) 2011*

Screening of advanced interspecific derivatives for resistance to late leaf spot: To evaluate groundnut interspecific derivatives for resistance to LLS, 96 selections from four wide crosses were screened for reaction to LLS under field conditions during the 2007 rainy season at ICRISAT, Patancheru. Field trials were laid out in a broad-bed-and-furrow (BBF) system with three replications. Plot size was 1.5 x 4 m, with inter-row spacing of 30 cm and plant to plant spacing of 10 cm within each row. TMV 2, a highly susceptible cultivar to LLS was used as an infector row and planted between every four test beds. Chemical sprays were used to control insect pests. At 53 days after sowing, plots were inoculated by application of conidial suspension of *Phaeoisariopsis personata* conidia. Following inoculation, perfo-irrigation was provided daily for 30 minutes in the evening for 30 days to create the high humidity required for optimum disease development. LLS severity was scored on a 1 - 9 rating scale at 75, 90 and 105 days after sowing. LLS disease development in the infector rows was uniform (good spatial distribution) and high in the infector rows with plants symptoms revealing severe infection at 105

days. Results showed highly significant differences amongst the test lines with coefficient of variations in the range of 10.3 to 14.5%. Out of the 96 inter-specific derivatives from 4 wide crosses, 58 had a score of 3 - 4, 24 recorded ratings between 4 - 5, and 14 between 5 - 6 at 105 days after sowing. The disease severity in the susceptible check, TMV 2 averaged 9 at 105 days. Further data analysis is in progress.

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Components of resistance to LLS under controlled environmental conditions: To evaluate components of resistance to LLS, 15 interspecific derivatives selected from advanced field screening trials and eight breeding lines including susceptible check, TMV 2, were tested using the detached leaf technique. Plastic pots of 15 cm diameter were filled with alfisol and farmyard manure (4:1), and two seeds of each genotype were sown in each plot. The experiment was conducted in the glasshouse, replicated three times in a randomized complete design (RCD) with ten plants of each cultivar per replication. Temperatures in glasshouse ranged from 25 to 30° C. At 35 DAS, fully expanded third leaves of each accession were selected and excised at the pulvinous notch. The leaves were immediately dipped in sterile distilled water and planted in sand culture. The sand culture was prepared in plastic trays (39.5 x 29 x 7 cm) containing a layer of sterile sand (roughly 1.5 cm thick) with four glass rods placed to create five equal sections in the tray. Inoculum was prepared by suspending conidia in sterile distilled water with 10 drops L<sup>-1</sup> of the surfactant Tween 80 (polyoxyethylene sorbitan mono-oleate). The suspension was adjusted to a concentration of 30,000 conidia ml<sup>-1</sup> and applied to leaves with an atomizer. The following parameters were recorded and used for evaluating disease progress from 6 - 32 days after inoculation.

- a. Incubation period (days from inoculation to appearance of first symptom).
- b. Latent period (days from inoculation to the appearance of sporulating lesion).
- c. Lesion number (number of lesions on leaf surface).
- d. Leaf area damage (% comparison of test leaf damage with diagrams of leaves with known percentage of their areas affected).
- e. Lesion diameter (average diameter of four lesions measured at 30 days after inoculation).
- f. Infection frequency [number of lesions cm<sup>-2</sup> at 32 days after inoculation estimate obtained by measuring total number of lesions on each leaf and obtaining an estimate of the total leaf area using a leaf area meter (Model: 3100, LI-COR inc., Nebraska, USA). The ratio of number of lesions to the area of a leaf gave the infection frequency for that leaf].

Under glasshouse conditions, significant genotypic differences were observed for all components of resistance. Initial disease symptoms appeared first on leaflets of susceptible cultivars at 8 days after inoculation, the susceptible control TMV 2 showing earliest symptoms (8 DAI), followed by 4366-1 (16.2 days), and ARG-2 38/116 (16.7 days). Symptoms were expressed latest in ICGV 04095 (20.6 days), which was not significantly different from the resistant check, ICGV 86699. Similar trends were observed for the controls for all the components of resistance. Average incubation periods for the test genotypes ranged from 21.9 days (4366-3) to 27.6 days (ARG-2 36/149) compared to 19.1 and 30.7 days in the susceptible and resistant checks, respectively. All interspecific derivatives and breeding lines had longer incubation and latent periods, than TMV 2, the susceptible check. Genotypes ICGV 04095, ICGV 4371-5, ICGV 4531-2, ICGV 4531-4, ICGV 4371-3, ICGVCS 26-CS 52, ICGV 18-1, ICGV 4371-1 and ARG-2 33/113 - classified as resistant, had fewer lesions per leaf (9 - 25), smaller percent leaf area damage (2.2 - 6.1), smaller average lesion diameter (0.8 - 1.41), and lower infection frequencies (0.10 - 0.38) than the susceptible genotypes. On the other hand, genotypes 4366-6, ICGV 04060, ARG2 38/116, 4369-1, ICGV 04068, 4367-2, 4368-1, 4367-1, ARG2 15/46 and 4368-4 showed susceptibility for majority of the disease components as shown in Table 2.

**Table 2. Evaluation of components of resistance to *Phaeoisariopsis personata* in 24 groundnut genotypes under controlled environmental conditions.**

| Genotype | LAD (%) |       | Lesion number |      | IP   | LP   | LD30 (mm) | IF   |
|----------|---------|-------|---------------|------|------|------|-----------|------|
|          | LAD25   | LAD32 | LN25          | LN32 |      |      |           |      |
| 18-1     | 1.5     | 4.9   | 8.5           | 11.9 | 18.8 | 26.5 | 1.24      | 0.34 |
| 4366-1   | 1.9     | 5.8   | 16.4          | 26.9 | 17.7 | 22.8 | 1.21      | 0.26 |
| 4366-3   | 2.1     | 6.1   | 12.6          | 22.3 | 16.2 | 21.9 | 1.46      | 0.38 |
| 4366-6   | 1.2     | 7.7   | 12.7          | 28.8 | 17.7 | 25.0 | 1.36      | 0.46 |
| 4367-1   | 2.2     | 10.3  | 20.1          | 41.8 | 18.0 | 25.4 | 1.35      | 0.74 |
| 4367-2   | 1.0     | 8.2   | 13.1          | 36.5 | 18.0 | 26.8 | 1.15      | 0.54 |
| 4368-4   | 1.1     | 7.9   | 16.2          | 30.8 | 17.2 | 27.4 | 1.26      | 0.43 |



|              |      |      |       |       |      |      |      |      |
|--------------|------|------|-------|-------|------|------|------|------|
| 4368-1       | 2.0  | 11.5 | 16.8  | 34.9  | 17.7 | 25.5 | 1.31 | 0.74 |
| 4369-1       | 0.7  | 8.2  | 11.7  | 34.2  | 18.1 | 27.1 | 1.16 | 0.44 |
| 4371-1       | 0.4  | 3.1  | 4.4   | 17.1  | 17.7 | 27.2 | 0.80 | 0.20 |
| 4371-3       | 0.7  | 5.3  | 8.5   | 14.1  | 18.4 | 28.2 | 1.20 | 0.25 |
| 4371-5       | 0.3  | 3.1  | 5.4   | 9.0   | 18.3 | 26.0 | 1.00 | 0.15 |
| 4531-2       | 5.7  | 3.7  | 7.9   | 14.2  | 20.6 | 25.8 | 1.13 | 0.20 |
| 4531-4       | 0.3  | 4.0  | 7.0   | 13.6  | 17.9 | 25.1 | 1.14 | 0.25 |
| ARG-2 15/46  | 4.6  | 11.0 | 26.1  | 49.6  | 20.3 | 26.4 | 2.11 | 0.42 |
| ARG-2 33/113 | 3.3  | 5.5  | 10.6  | 20.3  | 20.4 | 26.1 | 1.44 | 0.25 |
| ARG-2 36/149 | 0.7  | 2.2  | 5.6   | 12.2  | 19.8 | 27.6 | 0.83 | 0.10 |
| ARG-2 38/116 | 7.8  | 10.3 | 26.7  | 34.6  | 16.7 | 23.6 | 1.86 | 0.43 |
| CS26-CS5-2   | 1.6  | 5.3  | 7.8   | 14.8  | 18.6 | 23.7 | 1.41 | 0.32 |
| ICGV 04060   | 5.6  | 9.5  | 25.1  | 45.4  | 19.7 | 26.0 | 1.81 | 0.41 |
| ICGV 04068   | 11.5 | 13.9 | 35.0  | 59.3  | 17.4 | 24.7 | 2.05 | 0.50 |
| ICGV 04095   | 1.0  | 2.5  | 5.5   | 9.0   | 20.6 | 27.1 | 0.91 | 0.14 |
| ICGV 86699   | 0.2  | 0.7  | 3.4   | 4.5   | 22.3 | 30.7 | 0.69 | 0.03 |
| TMV 2        | 13.5 | 18.2 | 38.6  | 55.4  | 11.8 | 19.1 | 3.2  | 0.48 |
| L.S.D (5%)   | 3.85 | 4.10 | 12.28 | 15.37 | 1.74 | 2.2  | 0.35 | 0.23 |
| CV%          | 149  | 66   | 92    | 65    | 11   | 10   | 29   | 72   |

LAD25 = Leaf area damage at 25 days after inoculation, LAD32 = Leaf area damage at 32 days after inoculation, LN25 = Lesion number at 25 days after inoculation, LN32 = Lesion number at 32 days after inoculation, IP = Incubation period (days), LP = Latent period (days), LD30 = Lesion diameter at 30 days after inoculation (mm), IF = Infection frequency (lesion cm<sup>2</sup>).

Genotypes classified as resistant (disease severity scores of 1-3 on the 1-9 scale) to *Phaeoisariopsis personata* exhibited longer incubation periods, longer latent periods, fewer lesions per leaf, smaller percent leaf area damage, smaller lesion sizes, and lower infection frequencies than susceptible genotypes. This is in accordance with the hypothesis of partial resistance, indicating that several components of resistance contribute to reduction in rate of epidemic development and progress.

F Waliyar and N Mallikarjuna

*Milestone: 8-10 selected advanced breeding lines in each country evaluated for local adaptation and farmer-preferred traits in farmers' fields in SAT Asia (Special Projects) (SNN/RA/FW) 2009*

**Evaluation of advanced breeding lines for local adaptation and farmer-preferred traits:** With the objective to select farmer-preferred varieties under moisture stress and popularize them, an Integrated Scheme of Oilseeds, Pulses, Oilpalm and Maize (ISOPOM)-funded (Government of India) project on "Farmers participatory groundnut improvement in rainfed cropping systems" was launched in 2006. The project is being implemented by ICRISAT and National Research Centre for Groundnut (NRCG) in three states, Andhra Pradesh (AP), Orissa and Gujarat. Anantapur and Chittoor districts were selected for project implementation in AP. A farmer participatory varietal selection (FPVS) trial consisting of 9 varieties (K 1271, K 1375, TCGS 888, TPT 25, ICGV # 00350, 00308, 86015, 91114 and a local control) was conducted in five villages (Varigireddipalli in Kadiri, Potharajukalava and Medhapuram in Anantapur, and Seenapagaripalli and Marikuntapalli in Chittoor) and also at all the three research stations (Agricultural Research Station, Kadiri and Anantapur, and Regional Agricultural Research Station, Tirupati) in AP. The trials from most of the villages failed due to acute drought in the 2006 rainy season. In the on station trial in Tirupathi, ICGV nos 00350 gave the highest pod yield among the genotypes. It gave 82% more yield than control K 134 (1367 kg ha<sup>-1</sup>). It had more number of primary branches and pods per plant than other genotypes. It also recorded the highest yield in two on-farm baby trials. In Anantapur, ICGV 00308 and ICGV 91114 gave 51% and 47% more yield than the widely grown variety JL 24. These two varieties also had higher haulm yields than JL 24. At Kadiri, ICGV 00308 and TPT 25 showed low susceptibility to stem rot. ICGV 00350 and K 1271 showed promise for pod yield, and K 1271 had higher haulm yield. Impressed by the performance of ICGV 00350, both in farmers fields and at research stations. RARS Tirupathi has proposed it for inclusion in the Initial Varietal Trial (IVT) of the All India Coordinated Research Project on Groundnut. During the postrainy season, sufficient quantity of seed was multiplied in farmer fields and the produce was procured at all the three locations. During the 2007 rainy season, in addition to the existing villages, where Mother-baby trials were taken up, one more village in each district (Nagasamudram in Anantapur, Sunnapuguttathanda in Kadiri, and Rajuvaaripalli in Chittoor) was also

included in the project. During the field days organized in each of these villages, ICGV 00350 and ICGV 91114 were liked by the farmers in all the three districts. Details on post harvest observations would be available later .  
SN Nigam and R Aruna

*Milestone: Wild Arachis species evaluated for tobacco streak virus (TSV) resistance and durable resistant genotypes identified (FW/SNN/RA) 2007*

**Evaluation of wild *Arachis* species for tobacco streak virus (TSV) resistance:** Stem necrosis disease caused by Tobacco Streak Virus (TSV), first recognized in the year 2000, has emerged as a significant threat to groundnut cultivation in India. All cultivars currently grown in India are highly susceptible to TSV. This study sought to evaluate wild relatives (*Arachis* spp.) of groundnut to identify potential sources of resistance to TSV. Fifty-six germplasm accessions from 20 wild *Arachis* spp. representing four sections (*Arachis*, *Erectoides*, *Procumbente* and *Rhizomatosae*) along with susceptible cultivars JL 24 and K 1375 were evaluated for resistance to TSV under greenhouse conditions using mechanical sap inoculations. Systemic virus infection determined by ELISA in the test accessions ranged between 0 and 100 %, with 24 accessions in Section *Arachis* having less than 35% incidence. Results of the repeated trials in the greenhouse detected systemic infection in 48 accessions, while eight of these accessions were negative for TSV infection. The eight accessions were ICG 8139, 8195, 8200, 8203, 8205 and 11550 belonging to *A. duranensis*; ICG 8144 belonging to *A. villosa*; and ICG 13210 belonging to *A. stenosperma*. These results suggested that these accessions could be used as parents in a crossing program to transfer TSV resistance into cultivated genotypes.

F Waliyar, P Lava Kumar, SN Nigam and R Aruna

*Milestone: Five interspecific derivatives of groundnut evaluated for TSV and peanut bud necrosis virus (PBNV) diseases and promising lines identified (NM/FW/ SNN/RA) 2010*

**Evaluation of interspecific derivatives for Tobacco Streak Virus (TSV) and peanut bud necrosis virus (PBNV):** Fifty two advanced generation interspecific derivatives with *Arachis diogeni*, *A. cardenasii* and *A. batizocoi* as one of the parents in generating the derivatives, were tested for resistance to peanut-bud-necrosis-virus, which causes PBNV, by standard procedures developed for groundnut. All the test plants and controls developed chlorotic spots on the inoculated leaves after 6 days of inoculation confirming successful challenging with the virus. Plants were monitored at weekly intervals for the presence and spread of virus by DAC ELISA technique and disease symptoms on the plants by visual observation. Eight lines (3166, 4678, 4877, 3124, 4864, 4876, 3167 and 4667) did not show any PBNV disease symptoms and tested negative for the presence of virus in DAC ELISA tests. Lines 4510 (11%), 3130 (20%), 3134 (11%) and 4677 (33%) had varying percentages of damage due to PBNV, compared to total infection (100%) in the controls. Three lines of advanced generation interspecific derivatives, with *A. villosa* as one of the parents, comprising 7 plants in each line were screened for peanut stem necrosis disease caused by tobacco streak virus (TSV). The lines were derived from *A. villosa* as one of the parents. *Arachis villosa* has been identified as one of the wild species resistant to Peanut stem necrosis disease. The test plants and the controls were challenged with the virus. All the plants developed necrotic spots on the inoculated leaves 6 days after inoculation confirming successful challenging with the virus. Plants were monitored at weekly intervals for the systemic spread of the virus by DAC ELISA and disease symptoms visually. One plant from each line did not show the presence of virus as well as disease symptoms. Rest of the controls and the test plants showed the presence of Virus as well as disease symptoms.

F Waliyar, N Mallikarjuna and P Lava Kumar

In another trial, 21 plants from three interspecific derivatives were evaluated for resistance to TSV and PBNV during the 2007 rainy season. Subsequent to sowing in plastic pots, plants were dusted with carborandum and inoculated 30 days after sowing (plants were at 3 - 4 leaf stage) with TSV at 1/30 dilution. Plants were then washed with tap water to remove excess carborandum. Six plants of variety JL 24 were used as controls. Test plants were monitored and rated at weekly intervals for viral symptoms and spread patterns, and direct antigen coated (DAC) ELISA was used to determine presence or absence of viral particles. All test plants and controls developed necrotic symptoms six days after inoculation. Plants developed symptoms characteristic of TSV including veinal and stem necrosis 10-12 days after inoculation. Disease incidences ranged from 85 – 100% in test plants compared to 90 - 100 % in controls. These results indicate that all three derivatives are susceptible to TSV infection.

For evaluation for resistance to PBNV, 487 plants derived from 52 interspecific derivatives were screened for resistance to PBNV. Individual plants were sown and raised in plastic pots. At one month after sowing, plants were tested for PBNV by DAC ELISA procedure. The virus dilution used for inoculation was 1/10. Test plants

were monitored and rated at weekly intervals for viral symptoms and systemic spread of the disease, and DAC ELISA used to determine presence or absence of viral proteins. Findings confirmed successful inoculation of plants with PBNV, since all test plants and controls developed characteristic PBNV symptoms on inoculated leaves at 5 - 6 days after inoculation. Genotypes 3166, 4678, 4877, 3124, 4894, 4876, 3167 and 4667 did not reveal disease symptoms. These findings were confirmed by ELISA results, which returned negative results. Three genotypes derived from interspecific crosses displayed a lower incidence (0 - 20%) as compared to the positive control (90-100%). Promising derivatives (showing low percent infection) will be re-evaluated in the coming season with larger populations to confirm the results.

F Waliyar, N Mallikarjuna and SN Nigam

*Milestone: Field trials of stable and promising derivatives for TSV and peanut bud necrosis diseases conducted in Anantapur and other target locations (NM/FW/SNN/RA) 2012*

Promising interspecific derivatives exhibiting high levels of resistance to TSV and PBNV will be tested in the field trials during the 2008 rainy season. This work is currently underway in the glasshouse and the next step will be to screen this germplasm set in the field on-station and in farmers' fields.

F Waliyar

**Activity GN 6A.1.2: Develop a better understanding of inheritance of components of resistance to late leaf spot (LLS), confectionery traits and traits associated with drought tolerance (specific leaf area (SLA) and SPAD chlorophyll meter reading (SCMR))**

*Milestone: Knowledge of inheritance of components of resistance to LLS in three crosses gained and appropriate breeding strategy devised (SNN/RA/FW) 2008*

**Inheritance of components of resistance to LLS:** Two LLS resistant germplasm lines (ICG 11337 and ICG 13919) and a susceptible variety JL 24 were used as parents in straight and reciprocal crosses for developing the materials for studying inheritance of components of LLS resistance. Observations on parents, F<sub>1</sub>, F<sub>2</sub> and F<sub>3</sub> plants were recorded during the 2006 rainy season both under controlled environmental conditions through detached leaf technique and in the field in sick plot. Both direct and reciprocal crosses were evaluated in all the crosses. In the absence of reciprocal differences in both the crosses, the data from populations was pooled to analyze for gene effects and gene action.

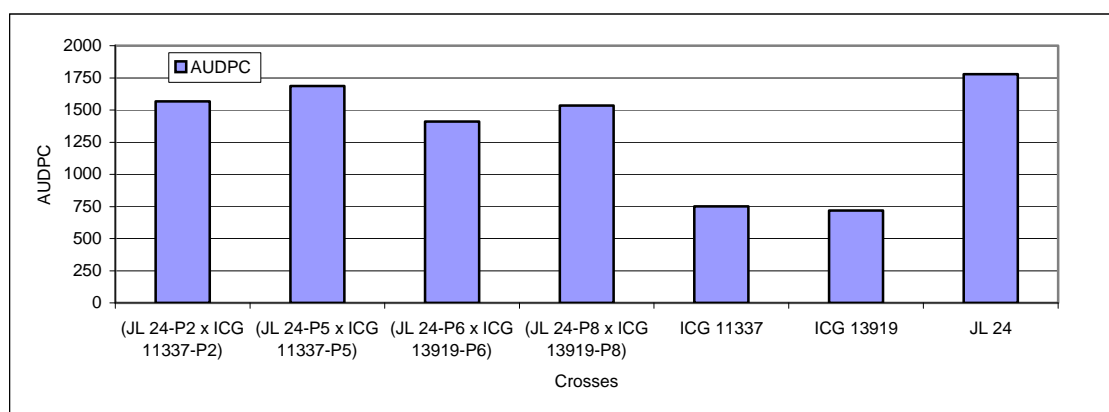
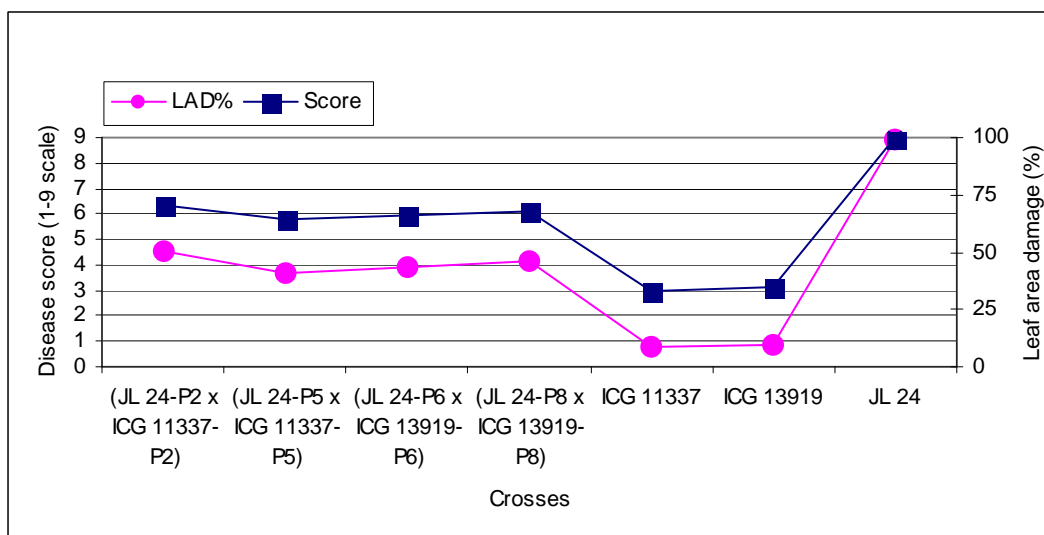
The gene action of various components of resistance (such as incubation period, latent period, leaf area damage, and number of lesions) was studied in both the crosses. Both additive and dominance gene action were significant and the maximum variation for incubation period and latent period. The leaf area damage was largely governed by additive gene action. The number of lesions was largely governed by additive gene action in ICG 11337 x JL 24 and non-allelic additive x dominance gene action in ICG 13919 x JL 24 (Table 3).

**Table 3. Inheritance of components of resistance to late leaf spot in groundnut.**

| Crosses                   | No of progenies | AUDPC |      |      |      |     |     |      |     |     |
|---------------------------|-----------------|-------|------|------|------|-----|-----|------|-----|-----|
|                           |                 | Mean  | Min  | Max  | Mean | Min | Max | Mean | Min | Max |
| (JL 24-P2 x ICG 11337-P2) | 166             | 1567  | 500  | 2581 | 6    | 2   | 9   | 51   | 5   | 95  |
| (JL 24-P5 x ICG 11337-P5) | 18              | 1687  | 816  | 2485 | 6    | 3   | 8   | 41   | 10  | 80  |
| (JL 24-P6 x ICG 13919-P6) | 134             | 1411  | 568  | 2265 | 6    | 2   | 9   | 43   | 5   | 95  |
| (JL 24-P8 x ICG 13919-P8) | 118             | 1534  | 511  | 2459 | 6    | 4   | 9   | 46   | 10  | 95  |
| ICG 11337                 | -               | 752   | 647  | 935  | 3    | 3   | 3   | 9    | 6   | 10  |
| ICG 13919                 | -               | 719   | 593  | 813  | 3    | 3   | 4   | 10   | 6   | 12  |
| JL 24                     | -               | 1779  | 1553 | 1987 | 9    | 9   | 9   | 100  | 95  | 100 |

\*Late leaf spot disease score on 1 – 9 scale. LAD = Leaf area damage (%) at 110 days after sowing.

Leaf area damage varied from 7.5 to 95.5%. AUDPC ranged from 615 to 2285 among the progenies at 110 DAS (Figure 2a, b).



**Figure 2. Reaction of F<sub>3</sub> groundnut crosses (mean of all progenies) at 110 days after sowing to late leaf spot (a) disease severity scores and leaf area damage (b) area under disease progress curves (AUDPC).**

F Waliyar, SN Nigam and R Aruna

*Milestone: Knowledge of inheritance of traits associated with drought tolerance in three crosses gained and appropriate breeding strategy devised (SNN/RA/VV) 2009*

**Inheritance of traits associated with drought tolerance:** To study inheritance of traits associated with drought tolerance, four crosses (ICGV 76 x ICGV 93291; ICGV 99029 x ICGV 91284; JL 24 x ICGV 86031 and ICR 48 x ICGV 99029) and their reciprocals were made involving diverse parents with high and low values of SCMR (SPAD Chlorophyll Meter Reading) and SLA (Specific Leaf Area). F<sub>1</sub> plants have been produced and backcrosses with both the parents were attempted in the 2006/2007 postrainy season. The material would be planted and observation taken in the 2007/08 postrainy season to carry out inheritance studies on SLA and SCMR.

SN Nigam, R Aruna and V Vadez

*Milestone: Knowledge of inheritance of confectionery traits in two crosses gained and appropriate breeding strategy devised (SNN/RA) 2009*

To study the inheritance of confectionery and quality traits (seed characteristics, O/L ratio, oil and protein content, and blanchability), parents, F<sub>1</sub>, F<sub>2</sub> and backcrosses of two crosses (Chico x ICGV 01393 and Chico x ICGV 02251) along with their reciprocals were sown in a replicated trial during the 2006/2007 postrainy season. Observations were taken on different seed characters, and 100-seed weight. The trial along with the F<sub>3</sub> progenies would be evaluated during the 2007/08 postrainy season.

*Milestone: Three mapping populations for LLS and two for confectionery traits developed (RA/SNN) 2009*

Three mapping populations (ICG 11337 x JL 24, ICG 13919 x JL 24, and ICG 11337 x ICG 13919) involving diverse parents for reaction to LLS have been developed and the material is in F<sub>4</sub> stage. One of the mapping populations would be genotyped and phenotyped in the next season. Two populations (ICGV 01393 x Chico and ICGV 02251 x Chico) for confectionery traits have been developed and the material is in F<sub>4</sub> stage.

SN Nigam and R Aruna

*MTP output target 2007 6.1.1 GN 100 transgenic events of groundnut with TSVcp gene developed and screened in contained greenhouse (KKS/FW/SNN)*

*Internal output target GN 6A.2: Promising transgenic events of groundnut for resistance to TSV and PBNV available for commercialization and introgression in locally adapted germplasm*

**Activity GN 6A.2.1: Develop transgenic events of groundnut for resistance to TSV and evaluate their performance under contained greenhouse and field conditions**

Groundnut stem necrosis disease (GSND) caused by TSV has emerged as a serious problem on groundnut in Andhra Pradesh and Karnataka in India. All the currently grown groundnut varieties are susceptible to this virus. Biotech approach has been initiated to engineer resistance to TSV in groundnut by using the TSV coat protein (*TSVcp*) gene through *Agrobacterium tumefaciens*-mediated genetic transformation where several (112) putative transgenic events of popular groundnut cultivars JL 24, TMV 2 and ICGV 91114 were developed. PCR analysis confirmed integration of TSV CP transgene in 92 out of 112 events developed (73.6%). Further, ELISA/western analysis showed significant expression of CP in at least 32 transgenic events. More recently, the TSVCP gene driven by the CaMV 35S promoter was also sub-cloned into the pZP100 vector (Marker-free) and mobilized onto *Agrobacterium tumefaciens* strain C58. The generation of marker-free transgenic plants of groundnut with this vector has been initiated.

Leaf material from each progeny was collected prior to virus challenging, and tested by PCR analysis using TSVcp specific primers to determine the segregation pattern. In a batch-wise screening (10 events per batch), progenies from 22 transgenic events were evaluated for virus protection under contained greenhouse conditions. At the 3-leaf growth stage (8 - 10 day old plants), the test plants along with susceptible controls (JL 24) were dusted with carborandum and inoculated by standard mechanical sap inoculation procedure using 1:30 (w/v) TSV-affected French bean leaf sap extracts. After inoculation, plants were washed with tap water to remove excess carborandum. All test plants and controls developed necrotic symptoms 6 days after inoculation. Symptoms observed included veinal necrosis and stem necrosis, at 10 - 12 days after inoculations. Test plants were subsequently monitored at weekly intervals for virus spread and symptoms. These plants were tested by DAC ELISA for the presence of virus. All the inoculated plants developed necrotic symptoms on the inoculated leaves 7 days post-inoculation and tested positive to TSV with ELISA. Progenies from 7 events (31B, 47F, 48A, 48D, 48E, 48F, 1-1, 1-4, 4-6, 9-2, 9-3, 9-4 and 30-6) did not display any systemic symptoms, confirmed by negative results when tested by DAC ELISA. The fact that TSV was detected in the inoculated leaves of these plants and the lack of virus in the subsequently emerged leaves suggests blockage in the systemic spread of virus which seems to be responsible for the virus resistance. Progenies from 6 events delayed symptom expression by 2 to 3 weeks, compared to control groundnut plants. These plants apparently had normal growth pattern. It is likely that these plants may also have some resistance. A comprehensive evaluation of these events is being continued and trials will be repeated with event numbers 48, 1 and 9 to confirm the above results. At present, 20 additional events are under screening process in contained greenhouse conditions.

*Milestone: At least 10 promising TSVcp transgenic events identified and the disease resistance characterized under contained green house conditions (KKS/FW/SNN) 2008*

Three promising TSVcp transgenic events have been identified under contained greenhouse conditions. Further work is in progress to identify other transgenic events showing adequate levels of disease resistance.

*Milestone: Five promising TSVcp transgenic events identified and the disease resistance characterized under contained field conditions (KKS/FW/SNN) 2009*

Promising events of TSVcp transgenics will be available by 2009 for contained field trials.

**Milestone: Two best transgenic events with resistance to TSV used for introgression into locally adapted groundnut genotypes and their evaluation (KKS/FW/SNN/RA) 2010**

Introgression of TSVcp transgenic resistance events will commence at later stage.

**Milestone: Commercialization package for groundnut with transgenic resistance to TSV available for deployment (KKS/FW/SNN/RA) 2011**

This work will commence in 2009 as a follow-up to work currently underway in contained field trials. The work will focus on development and commercialization packages.

KK Sharma, F Waliyar, P Lava Kumar and SN Nigam

**Activity GN 6A.2.2: Develop transgenic events of groundnut for resistance to PBNV and evaluate their performance under contained greenhouse and field conditions**

*Milestone: 100 transgenic events of groundnut with PBNVcp gene or alternative gene developed and screened in contained greenhouse (KKS/FW/SNN/RA) 2008*

*Milestone: At least 10 promising transgenic events identified and resistance to PBNV characterized under contained greenhouse conditions (KKS/PLK/SNN/RA) 2009*

Peanut bud necrosis disease (PBNV) is an economically important virus disease of groundnut caused by *Peanut bud necrosis virus* (PBNV), transmitted by thrips, for which no durable resistance is available in the groundnut germplasm. Transgenic approach was undertaken to transfer resistance to PBNV using nucleoprotein (*PBNVnp*) gene in groundnut cultivar JL 24. Forty-eight independent transgenic events were produced by using two binary vectors encoding for *PBNVnp* gene through *Agrobacterium tumefaciens* and micro-projectile mediated genetic transformation. Overall, 24 groundnut transgenic events (12 biolistic mediated gene transfer and 12 *Agrobacterium* mediated gene transfer) along with control untransformed JL 24 plants were planted in the glasshouse. Symptom appearance was delayed by 2 to 3 weeks in the transgenic plants compared to the controls. Although all the infected transgenic groundnut plants showed severe PBNV symptoms, eight plants from the events B 8, B 9, B 11, B 13, B 15, B 19, B 20 and B 22 showed recovery, suggesting some tolerance to PBNV. Of the 24 events tested, event numbers 3, 4, 7 and 11 (20%) showed lower disease incidence compared to control, JL 24 (90%). The T<sub>2</sub> progenies from these promising transgenic groundnut events were selected for further molecular evaluation and screening.

Apparent lack of resistance to PBNV in transgenic plants could be attributable to the presence of RNA silencing suppressor gene (NSs) in the PBNV genome, which could be rendering *PBNVnp* gene ineffective. Therefore, as an alternate strategy based on RNAi and/or antisense, the development of PBNV resistant groundnut cultivars is under progress. For this, the PBNV NP gene in an antisense orientation driven by 35SCaMV promoter was cloned in a marker-free plasmid (pZPP200) and mobilised into *Agrobacterium tumefaciens* strain C58 for the transformation of tobacco as a model system and groundnut. In addition, strategies are being developed to use RNAi constructs for conserved domains of PBNV replicase, nucleoprotein, or movement genes, combined with RNAi constructs to counter and NSs gene for inducing RNAi-mediated resistance to PBNV in groundnut and other crops susceptible to this virus.

*Milestone: Five promising PBNVcp transgenic events identified and the disease resistance characterized under contained field conditions (KKS/FW/SNN/RA) 2009*

Eleven transgenic events of groundnut cultivar, JL 24 developed through biolistic mediated transformation, 13 *Agrobacterium* mediated transformation events and non transgenic groundnuts, JL 24 and ICGV 86031 (controls) were screened for resistance to Peanut bud necrosis virus in the field during rainy season of 2007. Seeds from each event were sown in 2 row plots spaced at 30 cm between plants and 50 cm between rows. Each event was replicated three times in a randomized complete block design (RCBD). Plots were contained by wire mesh up to a height of 2 m and a gate provided to ensure containment while facilitating entry for observations. In addition, standard biosafety precautions were effected. These included two rows of non-transgenic groundnut (JL 24) planted around the field perimeter for gene flow, if any, and two rows of sorghum planted beyond this to prevent any pollen drift due to wind. PBNV was propagated by natural infection (thrips). Data were recorded on disease variables including disease incidence and severity. Samples from symptomatic and asymptomatic plants

were collected and tested by DAC ELISA for the presence or absence of virus particles. Preliminary results revealed two events (PBNV (B)-1 and PBNV (B)-11) with low disease incidence in comparison to positive controls.

*Milestone: Two best transgenic events with resistance to PBNV used for introgression into locally adapted groundnut genotypes and their evaluation (KKS/FW/SNN/RA) 2011*

This work has not yet been started.

KK Sharma, F Waliyar and SN Nigam

## **Chickpea**

*Internal output target CP 6A.1: 50-100 chickpea breeding lines with high yield, improved seed traits and resistance to one or more biotic stresses [Fusarium wilt (FW), Ascochyta blight (AB), Botrytis gray mold (BGM) and Helicoverpa pod borer] developed and disseminated to NARS*

### **Activity CP 6A.1.1: Develop chickpea breeding lines (desi and kabuli) with enhanced resistance to AB, BGM and FW**

*Milestone: 15-20 new high yielding FW resistant desi and kabuli chickpea breeding lines made available to NARS annually (PMG/SP) Annual*

**International chickpea screening nurseries (ICSNs) of desi and kabuli chickpeas:** One ICSN-Desi and one ICSN-Kabuli were constituted and a total of 73 sets of these nurseries (36 ICSN-desi and 37 ICSN-kabuli) were supplied to NARS across 11 countries (Brazil, Canada, China, Ethiopia, India, Iraq, Myanmar, Nepal, Pakistan, Portugal and South Africa) for evaluation during 2006-07. Each nursery consisted of 18 entries and 2 checks – one common check (JG 11 in ICSN-desi and KAK 2 in ICSN-kabuli) and one local check. The entries were evaluated in a randomized complete block design (RCBD) with two replications. Each plot had four rows of 4 m length. One set of each nursery was evaluated at ICRISAT – Patancheru. As part of ICAR-ICRISAT project, an annual report of ICSNs was prepared from the Indian locations and distributed to all the collaborators during the annual group meeting of All India Coordinated Research Project on Chickpea. The most promising breeding lines identified from ICSN-desi included ICCV 04111, ICCV 03203, and ICCV 06102, while in ICSN-kabuli, ICCV 03407, ICCV 05303 and ICCV 06301 were most promising.

PM Gaur

**Development and evaluation of improved breeding lines of desi and kabuli chickpea:** Over 170 advanced breeding lines of desi and kabuli chickpeas were evaluated in two advanced yield trials (AYTs) and eight preliminary yield trials (PYTs) during the post-rainy season 2006/07. Two most promising lines identified in AYT-kabuli were ICCX-990027-F3-BP-9-BP and ICCX-990026-F3-BP-40-BP. These lines outyielded the best check, JGK 1, and had 100-seed weight more than that of KAK 2 and high level of FW resistance. In AYT-desi, the line ICCX-970047-BP-BP-P72-BP-BP-BP outperformed the best check, JG 11 with respect to seed yield and 100-seed weight. Of the 143 advanced breeding lines of desi chickpea evaluated in 8 PYTs, the most promising lines identified were ICCX-000008-BP-BP-P19-BP, ICCX-000031-BP-BP-P4-BP, ICCX-000008-BP-BP-P124-BP and ICCX-000031-BP-BP-P22-BP. These lines were superior to the best check with respect to yield, 100-seed weight, and resistance to Fusarium wilt (FW).

PM Gaur and S Pande

**Resistance for Fusarium wilt in desi and kabuli chickpea advanced breeding lines:** We evaluated 28 F<sub>4</sub> populations of desi, 37 F<sub>4</sub> populations of kabuli, 8 F<sub>4</sub> populations of ISOPOM project, 122 F<sub>4</sub> early maturing progenies, 115 (105 + 10) F<sub>4</sub>/F<sub>5</sub> single plant progenies, 71 advanced breeding lines, 84 crossing block entries, 69 entries from Dharwad, 60 COGGO trial entries, 60 PYT-2 entries, 281 trial entries (20 PYT-1 desi, 20 PYT-2 desi, 20 PYT-3 desi, 20 PYT-4 desi, 20 PYT-5 desi, 20 PYT-6 desi, 20 PYT7 desi, 20 PYT-8 desi, 10 AYT-1 desi, 26 AYT-1 kabuli, 24 drought tolerant lines, 20 ICSN desi, 20 ICSN kabuli, 10 ISOPOM 1, 11 ISOPOM 2) for FW resistance under artificial epiphytotic conditions at ICRISAT-Patancheru.

Of the 28 F<sub>4</sub> desi, no line was promising for resistance to FW. Among kabuli populations, one population ICCX 030156-F<sub>4</sub> was resistant (<10%) to FW. All the eight F<sub>4</sub> populations-ISOPOM and 71 advanced breeding lines showed a susceptible reaction to wilt. Among F<sub>4</sub> progenies for earliness study, ICCX 37 and JG 11 had a resistant (<10%) reaction to FW. Of the 115 single plant progenies, ICCX 040081-F3-P4 was asymptomatic,

and ICCX 040124-F3-P1, ICCX 040027-F3-P4 and ICCX 040027-F3-P18 were moderately resistant (10 to 20%) to wilt. Among 84 crossing block entries, ICC 14194, JG 11 and AP 1 were asymptomatic, and 13 lines (ICCs 4958, 17109, ICCVs 95334, 03112, 05529, kabuli selection 3, KAK 2, JGK 1, ICC 37, ICCV 10, AP 5, and Sona) had a resistant reaction to wilt. Fourteen lines were moderately resistant (10 to 20%) to wilt.

ICCV nos. 93505, 93705 and 95702 were asymptomatic while ICCV nos. 96853, 98504 and 04609 showed resistant reaction to wilt. Five lines (ICCV nos. 96852, 98502, 98503, 98505 and 98506 were moderately resistant (10 to 20%) to wilt. Of the 60 PYT 2 entries, ICCV nos. 93954, and 96854 were resistant to wilt. Among 281 trial entries, 17 lines were asymptomatic to wilt. A total of 69 lines (7 from PYT 1 desi, 4 from PYT 2 desi, 7 from PYT 3 desi, 5 from PYT 4 desi, 2 from PYT 5 desi, 2 from PYT 6 desi, 6 from PYT 7 desi, 3 from PYT 8 desi, 1 from AYT 1 desi, 7 from AYT 1 kabuli, 3 from drought tolerant lines, 13 from ICSN desi, 8 from ICSN kabuli, 1 from ISOPOM trial 2) were resistant to FW.

**Evaluation of advanced wilt promising selections for resistance to Fusarium Wilt:** A total of 163 advanced selections were evaluated for resistance to wilt and root rots in a multiple disease sick plot (MDSP) during 2005-06 crop season following standardized screening technique. Of the 163 selections tested, six selections (ICCV nos. 96851, 05527, 05528, IGK 12, IGK 15, and IGRF 14) were asymptomatic and 67 selections were resistant (<10% wilt). Collar rot incidence was very low. Among these 96 were asymptomatic, and 67 resistant (<10%) to collar rot.

**Identification of wilt resistant kabuli chickpea breeding lines:** We evaluated 26 kabuli entries of the advanced yield trial-1 (AYT 1), and 20 entries of the International Screening Nursery-kabuli (ICSN) in wilt sick plot at ICRISAT-Patancheru. Among 26 entries of AYT 1, ICCX 990027-F3-BP-6-BP, ICCX 990024-F3-BP-10-BP, ICCX 990026-F3-BP-37-BP, ICCX 990026-F3-BP-40-BP, and ICCX 990027-F3-BP-36-BP were asymptomatic, and ICCX 990024-F3-BP-11BP, ICCX 990026-F3-BP-32-BP, ICCX 990026-F3-BP-34-BP, ICCX 990027-F3-BP-18-BP, ICCX 990027-F3-BP-24-BP, ICCX 990027-F3-BP-38-BP, KAK 2 were resistant to wilt. Of the 20 entries in ICSN, KAK 2 was asymptomatic, and ICCV nos. 03407, 04301, 04305, 05313, 06302, 06303, and 6306 and JGK 1 had resistant reaction.

**Wilt resistance in advanced breeding lines received from Australia:** A total of 71 advanced breeding lines and 10 standard checks were evaluated for wilt resistance in wilt sick plot. All lines were susceptible to wilt.

S Pande and PM Gaur

**ICAR-ICRISAT collaborative research on FW resistance in chickpea:** In collaboration with scientists from Indian Institute of Pulses Research, Kanpur, a total of 174 entries (58 IVT entries, 11 AVT entries, 9 DRR lines, 25 donor lines and 70 from National Nursery) were evaluated for FW resistance under field conditions, and AB resistance under controlled environment conditions using standard screening techniques. Of the 174 lines tested, 19 lines (IGD 8 from IVT desi, IGB 4, IGB 6 from IVT bold, IGL 3 and IGL 8 from IVT LS, IGEB 3 from IVT EB, IGRF 12 from IVG RF, ADG 5 from AVT desi, DRN 2, and DRN 7 from DRR lines, NNW 5, NNW 13, NNW 43, NNW 46, NNW 53, NNW 54, NNW 64, NNW 65, and NNW 68 from national nursery) were resistant (<10% wilt incidence).

S Pande and NARS Collaborators

**Australia-ICRISAT collaborative research for FW resistance in chickpea under COGGO project:** One hundred and fifty advanced breeding lines and 13 standard checks were evaluated for wilt resistance in wilt sick plot. Of these 150 entries tested, ICCV nos. 05526, 05530, 05533, 93505, 93705, 95702, 98502, 98503, 98504, and 98505 were asymptomatic, and 20 entries showed a resistant reaction (< 10% wilt).

S Pande/PM Gaur/KHM Siddique

**UAS Dharwad-ICRISAT collaborative research on wilt resistance in chickpea:** Two hundred and twenty two chickpea RILs received from UAS, Dharwad were evaluated for wilt resistance in wilt sick plot under artificial epiphytotic conditions. Segregation for wilt resistance among these RILs was observed as expected, and nine RILs were resistant (<10%) to wilt

S Pande and RL Ravi Kumar

*Milestone: 20-30 sources of resistance to FW, BGM and AB tested for stability across locations and pathotypes in Asia (SP/PMG) Annual*



Evaluation of chickpea wilt and root rot nursery (CWRRN) for resistance to wilt and root rots : Chickpea wilt and root rot nursery (CWRRN) consisting of 30 entries (28 wilt resistant + 2 wilt susceptible cultivars), was sent to 22 locations in India during 2006/07 season. Each entry was planted in one row, 4 m long, and replicated twice at all the locations, except in New Delhi, where the trial was planted in one replication. Data on wilt was recorded thrice at seedling, flowering, and at maturity stages of the crop.

Data from seventeen locations (Badnapur, Bangalore, Berhampore, Coimbatore, Dharwad, Gulbarga, Gurdaspur, Hazaribagh, Hisar, ICRISAT-Patancheru, Jabalpur, Junagadh, Kanpur, New Delhi, Rahuri, Raipur, and Sehore) was received and compiled. Incidence of wilt was low (<20%) at Dharwad and Hazaribagh, moderate (around 50%) at Bangalore and Coimbatore, and very high at other locations. Three lines (ICCV 03106, 03112 and 03207) in nine locations, two lines (ICC 12450 and ICC 14433) in eight locations, five lines (ICCs 12467, 14409, 16124, ICCVs 03205 and 04107) in seven locations, nine lines (ICCs 11322, 14344, 14404, 14432, 14436, ICCVs 03104, 03105, 03206 and 04109) in six locations, five lines (ICCs 12233, 14376, 14391, ICCVs 03111, and 04307) in five locations, three lines (ICCs 11324, 14434, and ICCV 03411) in four locations, and one line (ICC 14374) in three locations, were found resistant to wilt and root rots.

**Evaluation of International Ascochyta blight nursery for resistance to AB:** International Ascochyta Blight Nursery (IABN) 2006-07 consisted of 30 entries (29 promising entries identified under controlled environment conditions at ICRISAT-Patancheru, and one susceptible check). IABN was evaluated under field conditions at five locations (Dhaulakuan, Gurdaspur, Ludhiana, Hisar and ICRISAT-Patancheru) in India, and two locations (Islamabad and Attok) in Pakistan. Each entry was planted in one row of 2 - 4 m long and replicated twice. The nursery was artificially inoculated thrice at five-day intervals with conidial suspension @ 50,000 conidia ml<sup>-1</sup> at flowering and pod initiation stage of the crop in all locations. Evaluation at ICRISAT-Patancheru, was done under controlled environment conditions following standard techniques.

Data were received from all the locations, except Pakistan. Susceptible cultivar ICC 4991 exhibited a susceptible reaction (9 rating on 1-9 scale) at all the five locations in India. Eight entries (ICCVs 04530, 04537, 98818, ECs 516729, 516792, 516793, 517011 and 517025) in five locations; 10 entries (ICC 6373, ICCV 98815, ECs 516709, 516771, 516796, 516878, 516895, 516957, 516974 and 517039) in four locations; seven entries (ICCs 4033, 6304, 6945, ECs 517003, 516916, 516934 and 516967) in three locations; two entries (ICC 15996 and EC 517023) in two locations were resistant/moderately resistant to AB (< 5.0 rating). Two entries ICC 12968, and ICC 14344 were susceptible at all the five locations in India. At ICRISAT-Patancheru, high levels of resistance were not observed, but 22 entries were moderately resistant to AB.

**Evaluation of International Botrytis gray mold nursery for resistance to BGM:** The International Botrytis Gray Mold Nursery (IBGMN) was formulated [29 promising entries identified under controlled environment conditions at ICRISAT-Patancheru, and one susceptible check (ICC 4954)] during 2006-07. The nursery was evaluated under field conditions at one location in Nepal (Tarahara), two locations in Bangladesh (Ishurdi and Jessore), and three locations in India (Pantnagar, Ludhiana and ICRISAT-Patancheru). Each entry was planted in 2 - 4 m rows, and replicated twice. All the entries were artificially inoculated with conidial suspension of the local isolate at flowering and pod initiation stages of the crop at all the locations. At ICRISAT-Patancheru, the nursery was evaluated under controlled environment conditions following standard evaluation techniques.

Data was received from ICRISAT-Patancheru, Ludhiana and Pantnagar. Susceptible check showed highly susceptible reaction (9 rating on a 1-9 scale) at all the three locations. Seven entries (ICCVs 96853, 96859, 05604, 05605, 96817, ECs 516716 and 516738) were moderately resistant to BGM at ICRISAT-Patancheru and Pantnagar. At Pantnagar, two entries ICCV 96853 and ICCV 05604 were resistant (3 rating), and five entries (ICCVs 96859, 05605, 96817, ECs 516716 and 516738) had a moderate reaction (3.1 - 5 rating) to BGM. At ICRISAT-Patancheru, 24 entries were moderately resistant to BGM.

S Pande, PM Gaur and NARS Collaborators

**Purification and maintenance of virulence of isolates of *Fusarium oxysporum* f.sp. *ciceris*:** Forty-four isolates of *Fusarium oxysporum* f.sp. *ciceris* (FOC) collected from 18 locations in 11 states in India were purified for maintenance of virulence. Of these, 10 were from Andhra Pradesh (ICRISAT-Patancheru, Kurnool and Hyderabad), five each from Madhya Pradesh (Jabalpur and Sehore) and Uttar Pradesh (Kanpur and Pantnagar), four each from Haryana (Hisar) and Maharashtra (Badnapur, Rahuri and Akola), two each from Punjab (Ludhiana), Karnataka (Dharwad, Gulbarga) and Gujarat (Junagadh), one each from Bihar (Dholi), Delhi (New Delhi) and Himachal Pradesh (Dhaulakuan). Four races reported in 1982 from India were also included in this study. Pathogenicity test was done using a common susceptible cultivar JG 62, following standardized

evaluation technique under greenhouse conditions at ICRISAT-Patancheru. Isolations were made from freshly wilted seedlings and incubated at 25<sup>0</sup> C in the incubator for seven days. Pure cultures were selected and single spore isolates obtained following standardized mycological techniques.

**Pathogenicity characterization of isolates of *Fusarium oxysporum* f.sp. *ciceris*:** A total of 44 isolates collected from 19 locations in 12 states in India, were evaluated for pathogenic variation of *Fusarium oxysporum* f.sp. *ciceris* (FOC) using 17 cultivars having differential reaction to ICRISAT isolate. Four races, which were reported during 1982 from India, were also included in this study. The 17 cultivars used in this study were JG 62, C 104, L 550, K 850, Chafa, Annigeri, CPS 1, JG 74, BG 212, WR 315 (1982 differential lines), Pb 7, ICC 506, ICCV 2, 11311, 11312, 11313 and 12467 (new lines).

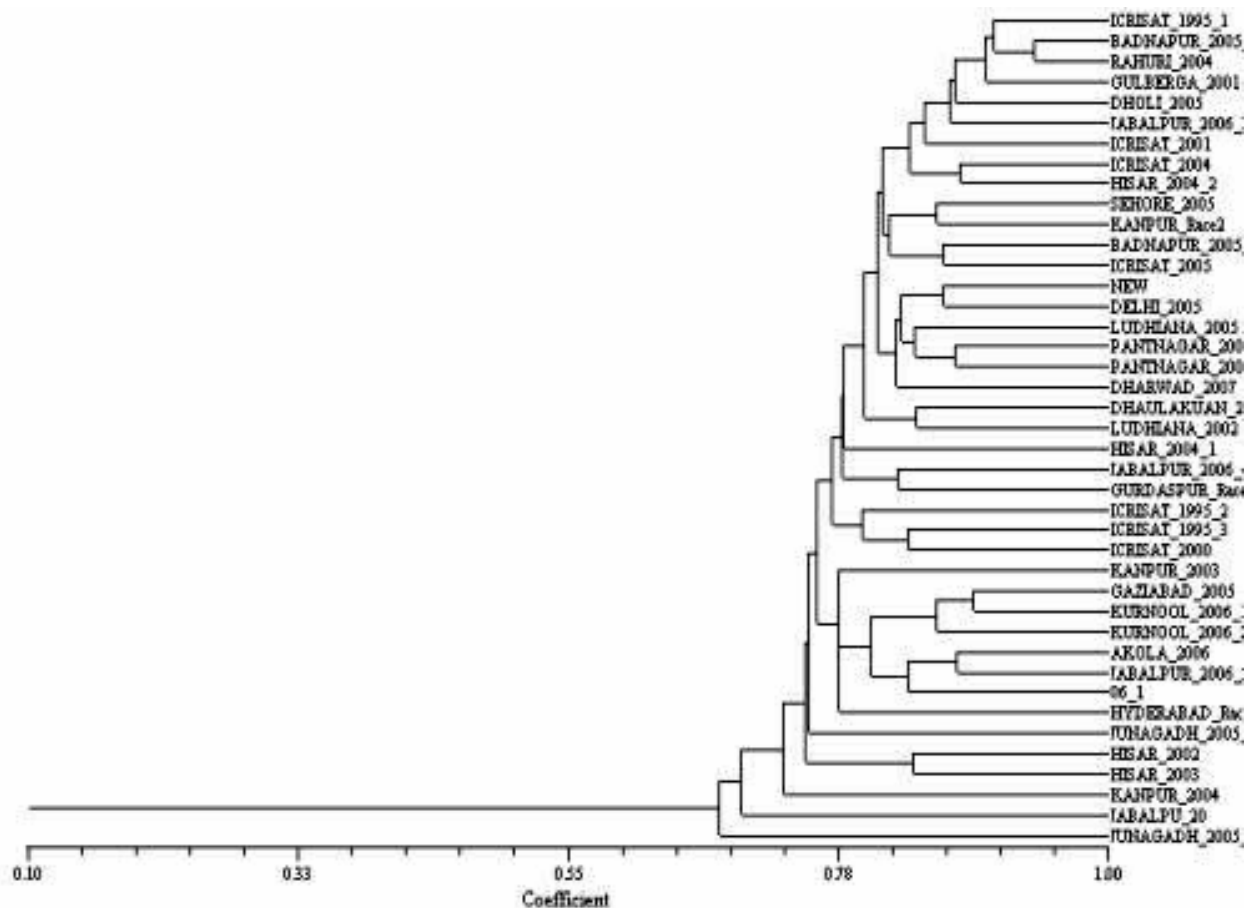
Standardized root dip technique was followed for inoculation. Seedlings were observed for 30 days for wilt development. Initial and final wilts in each pot and mortality due to wilt were recorded at weekly intervals. Preliminary studies indicated that out of 17 cultivars, nine (JG 62, C 104, L 550, K850, Chafa, Annigeri, CPS 1, JG 74, BG 212, WR 315 and ICC 506) differed significantly in their reaction to different isolates of FOC, and hence, were selected for use as differentials. However, work on selection of more differentials is in progress.

**Molecular characterization of Indian isolates of *Fusarium oxysporum* f. sp. *ciceris*:** Forty-eight isolates (41 pathogenic and 7 non-pathogenic) *F. oxysporum* f. sp. *ciceris* (FOC) collected from eleven states in India till 2006 were studied for genetic variation using Amplified Fragment Length Polymorphism (AFLP). Protocol for extraction of DNA was standardized. Genomic DNA was extracted from each isolate (pathogenic and non pathogenic) by the cetyltrimethylethyl ammonium bromide (CTAB) method. The AFLP analysis was carried out using the commercial kit (Gibco BRL, USA) following the manufacturer's protocols with slight modifications as described below. Primary template DNA was prepared in one-step restriction-ligation reaction. Fungal genomic DNA (400 ng) was digested with the two restriction endonucleases, *Eco*R1 and *Mse*I and ligated to *Eco*R1 and *Mse*I adapters. The ligation mixture was pre-amplified in a thermal cycler using a temperature cycle of 94 C for 30 s, 56 C for 60 s, and 72 C for 60 s in a total of 30 cycles. Selective primers provided in the kit were used and the amplification was carried out according to the manufacturer's protocol. The three *Eco*R1 primer (E-TC, E- TA and E-AC) and five *Mse*I (M-CAT, M-CAC, M-CAG, M-CTT and M-CTA) primers were used in six combinations for amplification. The *Eco*R<sub>1</sub> primer was labeled with [ $\gamma$ -<sup>32</sup>P]-ATP (3000 Ci/mmol) and auto radiograms were obtained using Kodak X-Omat film. Preliminary investigations indicated highly polymorphic profiles, and both inter- and intra-population variations were observed among the FOC isolates. Similarity coefficient in cluster analysis varied from 0.68 to 0.99 (Fig. 3).

S Pande, M Sharma, R Varshney and D Hoisington

**Purification and maintenance of virulence of pathotypes of *Ascochyta rabiei*:** A total of 19 isolates of *Ascochyta rabiei* collected from 12 locations in five states in India were purified for maintenance. Of the 19 isolates, four were from Ludhiana, two each from Hisar, Gurdaspur, Palampur and Sriganaganagar; and one each from Abohar, Ambala, Berthin, Dhaulakuan, Pantnagar, Ropar and Sundernagar. Pathogenicity of all these isolates was proved using a common cultivar Pb 7 following standardized evaluation protocol under controlled environment conditions (incubators). *Ascochyta rabiei* was reisolated from fresh stem lesions from each isolate. Pure cultures were selected and single spored following standard mycological techniques.

**Threshold and quantification of wilt and root rot pathogens of chickpea in wilt and multiple disease sick plots:** Quantification of wilt and root rot pathogens of chickpea was carried out in wilt sick plot [(WSP) (BIL 3 C)] and multiple disease sick plot [(MDSP) (BIL 1)] during 2006-07 at ICRISAT-Patancheru. Soil samples were collected up to 1 m depth before planting and after harvest of chickpea crop and were processed as in previous years. Fungal colonies and sclerotia of wilt and root rot pathogens were estimated by following standard mycological techniques. Number of colonies of *Fusarium oxysporum* f.sp. *ciceris* (FOC) were 1320 g<sup>-1</sup> soil in WSP (BIL 3C) and 1390 g<sup>-1</sup> soil in MDSP (BIL 1) before planting of the crop. The number increased and reached 3140 g<sup>-1</sup> soil in WSP and 3250 g<sup>-1</sup> soil in MDSP after harvest of the crop. FOC colonies were recovered up to 75 cm depth before planting, and up to 100 cm depth after harvest in both fields. In addition to FOC, root rot pathogens viz *Fusarium solani*, *Rhizoctonia bataticola* and *Sclerotium rolfsii*, were also recorded in WSP.



**Figure 3. Dendrogram showing clustering of single spore isolates of *Fusarium oxysporum* f.sp. *ciceris* based on AFLP analysis**

Soil collected from MDSP was also assessed for root rot pathogens, *Fusarium solani* (black root rot), *Rhizoctonia bataticola* (dry root rot) and *Sclerotium rolfsii* (collar rot) following standardized techniques. About 320 colonies of *F. solani* and 210 colonies of *R. bataticola*  $g^{-1}$  soil and four sclerotia of *S. rolfsii* from 10  $g^{-1}$  of soil were recovered from surface soil, collected before sowing of chickpea crop. These root rot pathogens were multiplied during the cropping period and reached 720  $g^{-1}$  soil of *F. solani*, 520  $g^{-1}$  soil of *R. bataticola*. Further, these two root rot pathogens were recovered up to 50 cm depth before planting, and up to 65 cm depth after harvesting of the crop, while *S. rolfsii* was recovered up to 20 cm before sowing and 25 cm after harvest of the crop. As earlier, number of colonies of all these pathogens decreased as the depth increased. A large increase in the number of propagules of wilt and root rot pathogens at crop harvest (February) indicated that the chickpea crop may support multiplication of these pathogens in the soil.

**Succession of wilt and root rot pathogens of chickpea in wilt and multiple disease sick plots:** Succession of occurrence of chickpea wilt and root rot pathogens in WSP and MDSP were confirmed during the current season. Methodology including check cultivars (early wilting JG 62, late wilting L 550 and resistant WR 315), sampling and isolations were similar to last year. Apparently healthy looking plants were sampled at 10-day intervals from 10 DAS till maturity and isolations were made on PDA from root tip, root hair, epidermis and cortex, vascular bundles, and collar region of each plant separately in both the fields.

In MDSP, all the plants of early wilting cultivar JG 62 at 30 DAS, and late wilting cultivar L 550 at 90 DAS completely died due to wilt, whereas the plants of WR 315 remained healthy till maturity. FOC was recovered from all the root parts of healthy looking JG 62 from 10 DAS, and from 20 DAS in L 550 till death of the plants. FOC was also found in root tip, root hairs and vascular bundles in resistant cultivar WR 315 at 40 DAS, and continued till maturity. Late infection and restriction of the fungus in the root portion may be due to the resistance of the cultivar to wilt pathogen. *Fusarium solani*-black root rot pathogen and *Sclerotium rolfsii*-collar rot pathogen were very active during high soil moisture and infect the crop at the seedling stage (from 10 to 30 DAS) and killed the plants. Warm temperatures and soil moisture stress encouraged dry root rot fungus,

*Rhizoctonia bataticola* (RB) to infect and cause rotting of roots. During the current season, dry root rot appeared from 40 DAS till maturity in both L 550 and WR 315. In both these cultivars, in addition to pure cultures of FOC and RB, a mixture of these two pathogens was also observed frequently. Presence and interaction of these two pathogens in a single plant may be responsible for death of the plants.

In WSP, FOC was present in all the root parts of apparently healthy looking plants of both JG 62 and L 550 from 20 DAS and continued till the death of the plants. All plants of the susceptible cultivar JG 62 completely wilted 30 DAS and 90 DAS in L 550 as in MDSP. WR 315 yielded FOC from root portion from 40 DAS as in MDSP. Additionally, a mixture of FOC and RB was also recovered from root portion of late wilting and resistant cultivars from 50 DAS. These results indicated that the death of the plants might also be due to interaction of both these pathogens. Though wilt fungus was predominant in wilt sick plot, low intensities of *F. solani*, and *S. rolfisii* in seedlings (up to 30 days after sowing) and *R. bataticola* from pod filling stage of the crop were recorded in both L 550 and WR 315.

S Pande and M Sharma

*Milestone: 5-10 new sources of resistance to AB and BGM identified (SP/PMG/NM) 2009*

**Ascochyta blight (AB) resistance in selected advanced breeding lines:** A total 260-advanced breeding lines including checks were evaluated under controlled environment, following standardized evaluation technique. All the advanced breeding lines were found susceptible to AB (>5.0 rating on 1 - 9 rating scale).

**Ascochyta blight (AB) resistance in F<sub>3</sub>, F<sub>4</sub> and F<sub>5</sub> populations:** A total of 38 F<sub>3</sub> generation of (18,774 plants), 43 of F<sub>4</sub> generation of (31,392 single plants), and 19 F<sub>5</sub> generation (18,432 single plants) were evaluated under controlled environment following standardized evaluation techniques. Of the 18774 single plants of F<sub>3</sub> generation, 2630 plants were found asymptomatic (completely free from AB). Among 31,392 single plants of F<sub>4</sub> generation, 3285 plants were asymptomatic. Of the 18,432 single plants of F<sub>5</sub> generation, 1256 single plants were symptomatic. All asymptomatic single plants were transplanted in pots and grown under controlled environment for advancing the generation, and to retest for resistance to AB.

**Ascochyta blight (AB) resistance in promising germplasm and breeding lines:** One hundred and ninety seven promising germplasm and breeding lines were evaluated for AB resistance under controlled environment. Eighty five lines were found to be moderately resistant (3.1 to 5 rating) to AB. However, high level of resistance was not observed in any of the promising lines evaluated.  
S Pande/PM Gaur

**ICAR-ICRISAT collaborative research on AB resistance:** In collaboration with IIPR, Kanpur, 85 lines (69 entries from AVT, 15 from AB nursery) were evaluated for AB resistance under controlled environment conditions. Among AVTs four entries IGB 5, AGK 3, IGRF 6 and IGRF 20 were found moderately resistant to AB by showing < 5 rating on 1-9 rating scale. Among the entries of AB nursery, four lines ABN 3, ABN 4, ABN 6, and ABN 7 were found moderately resistant to AB.

S Pande and Collaborators

**Australia-ICRISAT collaborative research for AB resistance:** In collaboration with CLIMA and COGGO, Australia, 128 chickpea advanced breeding lines were evaluated for AB resistance using whole plant as well as cut twig techniques under controlled environment at ICRISAT, Patancheru.

Among advanced breeding entries, six entries (ICCVs 04052, 04518, 04526, 04530, 04537, 05562) were found resistant (< 3 rating on 1-9 rating scale), and 86 entries had a moderately resistant reaction (3.1 to 5 rating on 1-9 rating scale) to AB. Almost similar type of reaction was recorded in several lines in both techniques (whole plant or cut twig), and hence any of the techniques can be used for evaluation of chickpea lines for resistance to AB.

Additionally, 50 advanced breeding lines were also evaluated for AB resistance under controlled environment using standardized cut twig technique. Of the 50 entries, eight entries (ICCX-900222-4ABR-BP-BP-BP, ICCX-900217-16ABR-BP-1ABR-BP, ICCX-900219-26ABR-BP-1ABR-BP, ICCX-910028-42ABR-BP-21ABR-BP-11ABR-BP, ICCX-910028-42ABR-BP-30ABR-BP-3ABR-BP, ICCX-910028-35ABR-BP-4ABR-BP-4ABR, ICCX-900217-16ABR-BP-1ABR-BP-P1-BP, ICCX-900218-13ABR-BP-2ABR-BP-P1-BP) were found moderately resistant to AB.

Another set of 81 advanced breeding lines received from Australia were also evaluated for AB resistance under controlled environment. High level of resistance was not found in these lines. However, 30 lines were found moderately resistant (3.1 to 5 rating on 1-9 scale), 36 lines were susceptible (5.1 to 7 rating) and 15 were found highly susceptible to AB.

S Pande, PM Gaur and KHM Siddique

**Identification of new sources of resistance to BGM in advanced breeding lines:** One hundred and thirteen advanced breeding lines were evaluated for BGM resistance following standardized evaluation technique under controlled environment at ICRISAT-Patancheru. High level of resistance was not recorded in any of the advanced breeding lines evaluated. However, 45 lines were found moderately resistant (3.1 to 5 rating on 1-9 rating scale) to BGM. Another set of 93 advanced breeding lines along with standard checks were also evaluated for BGM resistance under controlled environment. Of the 93 lines, 44 had moderately resistant reaction (3.1 to 5 rating on 1-9 rating scale) and the rest showed susceptible reaction.

**BGM resistance in promising germplasm and breeding lines:** A total of 332 (154 germplasm lines, 83 advanced breeding lines and 95 lines received from Australia) were evaluated for BGM resistance under controlled environment at ICRISAT-Patancheru. Of the 332 lines, 139 lines (58 from germplasm, 26 from advanced breeding lines and 55 from Australian lines) were found moderately resistant (3.1 to 5 rating on 1 - 9 rating scale) to BGM.

S Pande and PM Gaur

*Milestone: 10-15 kabuli chickpea breeding lines with extra-large seed (> 50 g 100 seed<sup>-1</sup>) and high resistance to FW developed (PMG/SP) 2009*

**Development of FW resistant extra-large seeded kabuli chickpea breeding lines:** Efforts are being made to develop extra-large (> 50 g 100 seed<sup>-1</sup>) kabuli breeding lines with resistance to FW. Large number of segregating populations were generated by crossing farmer-preferred chickpea cultivars with two FW resistant extra-large seeded Mexican germplasm, ICC 14194 and ICC 17109. F<sub>4</sub> populations of eight crosses (ICCV 2 x ICC 14194, ICCV 2 x ICC 17109, KAK 2 x ICC 14194, KAK 2 x ICC 17109, JGK 1 x ICC 14194, JGK 1 x ICC 17109, Vihar x ICC 14194 and Vihar x ICC 17109) were screened at ICRISAT in the wilt screening nursery. A total of 528 wilt resistant plants with good plant type were selected from the wilt sick field. F<sub>5</sub> progenies (374) from early maturing plants were grown as second crop during January-April 2007 for further advancement. The F<sub>6</sub> seeds of the 20 selected progenies were supplied for evaluation during 2007-08 to the four collaborating centers (Mahatma Phule Krishi Vidyapeeth, Rahuri; Indian Institute of Pulses Research, Kanpur; Indian Agricultural Research Institute, New Delhi and Punjab Agricultural University, Ludhiana) of the ISOPOM project, funded by the Ministry of Agriculture, Government of India. Eighteen new crosses were attempted during 2006-07. One of the parents in each cross was extra-large seeded kabuli germplasm line. The F<sub>1</sub>s of the crosses made during the 2005-06 season and in the greenhouse during off-season in 2006 were advanced during the crop season 2006-07. F<sub>2</sub> seeds were harvested from 26 crosses.

**Evaluation of farmer-grown extra-large seeded (> 50g 100 seed<sup>-1</sup>) kabuli chickpea cultivars:** Farmers in India are growing unknown extra-large seeded kabuli chickpea cultivars with seed size > 50g 100-seeds<sup>-1</sup>. These have probably come through import and farmers call these by various local names, such as 'Dollar' and 'Double Dollar'. Five samples of locally grown extra-large seeded kabuli cultivars collected from two districts of Andhra Pradesh along with six samples collected by other collaborating centers of the ISOPOM project were evaluated for FW resistance, yield, seed size and phenology during the post-rainy season 2006-07. All the entries, except AP 1 and the check KAK 2, had seed size greater than 50 g 100 seeds<sup>-1</sup>. The most promising entries with yield more than 1500 kg/ha along with high level of resistance to FW ( $\leq 10$  % mortality) were IPCK-1, Phule G 0515, AP 4, and Phule G 0517.

PM Gaur/S Pande

*Milestone: 15-20 desi and kabuli chickpea breeding lines with combined resistances to FW, AB and BGM developed (PMG/SP) 2010*

**Development of desi chickpea breeding lines with combined resistance to FW, AB and BGM:** In the project funded by Council of Grain Growers Organization Ltd (COGGO), Western Australia, efforts have been made to develop desi chickpea breeding lines with multiple disease resistance (FW, AB, and BGM). F<sub>4</sub> and F<sub>5</sub> single plant progenies (110), selected primarily on the basis of AB/BGM resistance and seed size, were evaluated at ICRISAT along with 10 controls (Sona, Moti, Sonali, Rupali, WACPE 2078, WACPE 2098, 97 CO 16-2, ICCV

96386 and ICCV 93954 from Australia, and ICCV 10 from India). One row of each line (4 m) was grown in normal field and one row in wilt screening nursery. One row of each line was screened for AB under field conditions at Punjab Agricultural University (PAU), Ludhiana (India). Forty lines had good seed size ( $>16\text{ g }100\text{ seed}^{-1}$ ) and were early maturing ( $\leq 120$  days). Seven lines had the desired combination of early maturity, seed size and resistance to AB ( $\leq 4.0$  score on 1-9 scale). Seventeen new crosses including 15 intercrosses among the selected AB resistant progenies and 2 single crosses were made during 2006/07 crop season for development of new breeding lines with multiple disease resistance. Seventy two  $F_2$ , 45  $F_3$ , 35  $F_4$  and 10  $F_5$  populations were also grown during the post-rainy season 2006-07. The  $F_3$  to  $F_5$  populations were screened for AB resistance and the resistant plants were transplanted in the greenhouse. About 1900  $F_4$  to  $F_6$  single plant progenies of AB resistant plants selected were supplied to WA for further evaluation during 2007-08.

PM Gaur, S Pande and CLL Gowda

Evaluation of advanced desi chickpea breeding lines for combined resistance to FW, AB and BGM: Advanced breeding lines (150) and 13 standard checks were evaluated individually for wilt, AB and BGM to identify multiple disease resistance to all these three diseases. The entries were screened for FW in wilt sick field under artificial epiphytotic conditions, and for AB and BGM under controlled environment conditions. Eleven lines (ICCVs 04512, 04513, 05525, 05526, 05527, 05528, 05529, 05530, 05531, 05532 and 05533) were found resistant to FW, AB and BGM. Thirty-one entries were moderately resistant to both AB and BGM.

S Pande and PM Gaur

### **Activity CP 6A.1.2: Develop chickpea breeding lines with resistance to *Helicoverpa***

*Milestone: 5-10 sources of resistance and advanced lines tested for stability of resistance across locations (in India, Myanmar & Ethiopia) (HCS/CLLG/PMG) 2009*

**International *Helicoverpa* Screening Nursery:** Using reliable field screening techniques developed at ICRISAT for screening against *Helicoverpa*, several resistant sources have been identified. The resistant (less susceptible) sources identified in field screening were used in crosses to transfer resistance in high-yielding varieties. A new set of ICSN-HR was formulated in 2006, including few lines found to show less susceptibility to pod borer. Most of the lines are of short-to medium-duration, adapted to environments similar to southern and central India (16 to 22°N latitudes). The objective is to evaluate promising *Helicoverpa* resistant selections in varying environments and to provide an opportunity to NARS partners for selections to be used as parents or as end products for direct testing and release. The trial with 25 chickpea genotypes, including two checks, was sent to six collaborators in India and one to Myanmar. From multilocation trial study, it appears that among the locations Myanmar had the lowest pod damage (3.4%). At Patancheru, highest yield ( $2,376\text{ kg ha}^{-1}$ ) was recorded. The highest pod damage (27%) and lowest yield ( $830\text{ kg ha}^{-1}$ ) was recorded in the ICC 3137 (susceptible check). Across the locations, none of the genotypes were better than ICC 506-EB (resistant check) for pod damage and yield. At some locations, ICC 506-EB (and other resistant lines) did not show high level of resistance, possibly because of the climatic conditions.

CLL Gowda, HC Sharma and PM Gaur

*Milestone: 5-10 lines with resistance to both FW and Helicoverpa identified (CLLG/HCS/SP) 2009*

**Breeding chickpeas for resistance to pod borer, *Helicoverpa armigera*:** We made 63 crosses (51 single crosses and 12 four way crosses) and have obtained about 40 seeds in each entry. We evaluated 346 ( $F_8$ -197,  $F_9$ -149) progenies in 2006/07 season, and selected 44 progenies for further testing. The selection of progenies was based on visual scoring for pod damage, and high yield in comparison to check varieties. The selected progenies include 26  $F_8$  and 18  $F_9$  progenies. They were sown as two trials (22 + 2) with Annigeri and ICCL 86111 as checks under natural infestation of *Helicoverpa* during 2007-08. Apart from this, we have sown 96  $F_2$ s and 63  $F_1$ s for generation advancement in 2007-08 post-rainy season.

CLL Gowda, HC Sharma and S Pande

*Milestone: Physico-chemical mechanisms of resistance to Helicoverpa identified and nature of inheritance studied (CLLG/HCS) 2012*

**Protein and protease inhibitor profiles of a diverse array of chickpea lines in relation to resistance to *Helicoverpa armigera*:** Thirty-eight morphologically diverse chickpea genotypes, including *H. armigera* resistant (ICC 506) and susceptible (ICC 3137) checks were subjected to protein profiling using gel electrophoresis. Data analysis is in progress.

HC Sharma

*MTP output target 2007: 6.1.2 CP Novel set of chickpea SSR markers developed*

In total 311 SSR primer pairs (ICCM series) were designed based on SSRs isolated from the SSR-enriched library in chickpea. The primer aliquots for these SSR primers have been distributed, before publishing the primer sequences, to several partners including Washington State University, USA (Fred Muehlbauer), Murdoch University, Australia (Richard Oliver), National Chemical Laboratory, Pune (Vidya Gupta), GenXPro/ University of Frankfurt, Germany (Peter Winter), and National Research Centre on Plant Biotechnology, India (Ramamurthy Srinivasan), Sardar Vallabh Bhai Patel University of Agriculture & Technology, Modipuram (Rajendra Kumar). A report on generation of these SSR markers has been published in e-SAT Journal of Agricultural Research (Varshney et al. 2007).

Apart from the above mentioned SSR markers, another effort has been made to isolate the SSRs from the Bacterial Artificial Chromosome (BAC) sequences (BES) in collaboration with University of California, Davis, USA. A total of 46,270 chickpea BAC end sequences, representing 33.2Mb genome size, were obtained from UC-Davis and surveyed for the presence of microsatellite using *MicroSATellite (MISA)*. In total, 6,845 SSRs were isolated from 33,217 kb BES at a frequency of 1 SSR per 4.85 kb. In this set, di-nucleotide motifs were the most abundant (37% of total SSRs), while tri-nucleotide motifs were second most abundant (~10% of total SSRs). Most di- and tri-nucleotide sequences were AT-rich (ie, TA and TAA), comprising ~2/3 of SSRs in chickpea. With the goal of enhancing the SSR repertoire in chickpea, primer pairs were designed for 1,344 chickpea SSRs (CaM series).

Both the ICCM and CaM series SSR markers are currently being screened on parental genotypes of inter- and intra-specific mapping populations of chickpea.

RK Varshney, Spurthi Nayak, Nicy Varghese,  
Doug Cook and Dave Hoisington

*Internal output target CP 6A.2: Molecular markers for AB and BGM resistance validated and for Helicoverpa resistance identified in chickpea.*

#### **Activity CP 6A.2.1: Mapping and marker-assisted breeding for diseases and insect resistance in chickpea**

*Milestone: One intra-specific RIL population for mapping AB resistance QTLs developed using contrasting parents (PMG/SP) 2008*

RIL mapping population is being developed from a cross between ICCV 04516 (resistant parent with AB score of 3-4 on 1-9 scale, where 1 = immune and 9 = highly susceptible) and Pb 7 (susceptible parent with AB score of 9). The F<sub>3</sub> progenies were grown during the poststray season 2006-07.

PM Gaur and S Pande

*Milestone: The reported markers for AB and BGM resistance QTLs validated in new populations (PMG/SP/RKV) 2009*

The work on this milestone will start after the development of the mapping population in 2008.

RK Varshney

*Milestone: One inter-specific (C. arietinum x C. reticulatum) RIL population for mapping Helicoverpa resistance QTLs developed (PMG/HCS) 2009*

An interspecific RIL mapping population is being developed from a cross between *C. arietinum* accession ICC 3137 (susceptible) and *C. reticulatum* accession IG 72953 (tolerant). The F<sub>2</sub>s were grown during the poststray season 2006-07, and F<sub>3</sub> progenies in the rainout shelter during June to September 2007. F<sub>4</sub> progenies (n = 246) are being grown in the greenhouse during October 2007.

PM Gaur and HC Sharma

*Milestone: QTLs for Helicoverpa resistance identified from C. arietinum x C. reticulatum RIL population (HCS/RKV/PMG) 2010*

**Evaluation of interspecific (*C. arietinum* x *C. reticulatum*) mapping populations for resistance to pod borer, *Helicoverpa armigera*:** Interspecific mapping populations derived from ICC 3137 (*C. arietinum*) x IG 727953 (*C. reticulatum*) (250 F<sub>2</sub>s), and ICC 4958 (*C. arietinum*) x PI 489777 (*C. reticulatum*) (135 lines) were evaluated for resistance to *H. armigera* under natural infestation in the field, and detached leaf assay under laboratory conditions. The F<sub>2</sub> plants (246) of the ICC 3137 x IG 727953 cross were planted in the field in solarized deep Vertisol soils. The plants were evaluated for pod borer resistance using detached leaf assay. Ten neonates were released on terminal branches inserted in 3% agar-agar substratum in a 250 ml plastic cup. Data were recorded on leaf feeding on a 1 – 9 scale (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), larval survival and larval weights after five days. There were three replicates for each plant. Leaf damage rating varied from 1.7 to 8.7 in the F<sub>2</sub> plants compared to 5.3 in IG 72953 and 4.0 in ICC 3137. The resistant check ICC 506 suffered a damage rating of 3.5 compared to 5.2 on the susceptible check, ICC 37. Weights of the larvae after 5 days of feeding ranged from 1.90 – 11.86 mg in the mapping population compared to 2.86 mg on IG 72953 and 7.76 mg on ICC 3137. The larvae weighed 5.08 mg on the resistant check, ICC 506 and 4.93 mg on the susceptible check, ICC 37. Low leaf feeding or larval weights on the cultivated chickpeas were due to differences in development as these were more mature at the time of bioassay than the progenies derived from the wild chickpea.

Sixteen seeds (F<sub>3</sub>s) from each of four F<sub>2</sub> plants each showing high, moderate, and low levels of susceptibility to *H. armigera* were planted in pots in the greenhouse along with the parents and the resistant and susceptible checks. At the vegetative stage, the plants were evaluated for *H. armigera* resistance using detached leaf assay. Leaf damage rating in the F<sub>3</sub> plants varied from 4.1 to 8.5 compared to 4.6 in ICC 3137, 2.3 in IG 72953, 2.3 in the resistant check, ICC 506, and 8.0 in the susceptible check, ICC 37. Larval survival ranged from 44.5 to 93% in the F<sub>3</sub> plants compared to 60% in ICC 3137, 50% in IG 72953, 43.3% in the resistant check, ICC 506, and 76% in the susceptible check, ICC 37; the larval weights in the F<sub>3</sub> plants ranged from 3.2 – 14.2 mg, 5.4 mg on IG 72953, 7.3 mg on ICC 3137, 3.6 mg on the resistant check, ICC 506, and 12.9 mg on the susceptible check, ICC 37.

In another population derived from ICC 4958 (*C. arietinum*) x PI 489777 (*C. reticulatum*), 135 lines along with the resistant and susceptible checks were evaluated for resistance to *H. armigera* under natural infestation in the field. Leaf damage rating varied from 1 to 6 in the mapping population compared to 1.0 in PI 489777 and ICC 4958, 3 in ICC 37, and 4 in ICC 3137. At maturity, the pod damage rating ranged from 2 to 9 in the mapping population compared to 6 in ICC 4958 and ICC 37, and 9 in ICC 3137. This population will be studied in greater detail in future to identify markers associated with resistance to *H. armigera*.

HC Sharma, PM Gaur and TJ Ridsdill-Smith

*Milestone: QTLs for AB and BGM resistance introgressed in 3-4 farmer-preferred and locally adapted cultivars (PMG/SP/RKV) 2011*

The work on introgression of AB and BGM resistance QTLs will start after validation of these QTLs in 2009.

RK Varshney

*Internal output target CP 6A.3: Interspecific derivatives with new sources of resistance to AB, BGM and Helicoverpa developed*

**Activity CP 6A.3.1: Advanced generation inter-specific derivatives with resistance to *Helicoverpa* and BGM generated using wild *Cicer* from different gene pools**

*Milestone: Strategies to cross wild *Cicer* between primary, secondary, and tertiary gene pools developed (NM) 2008*

*Milestone: Fifteen stable inter-specific derivatives using resistant wild *Cicer* from secondary gene pool generated and screened for *Helicoverpa*, AB, BGM and good agronomic characters under field conditions (NM/HCS/SP/PMG) 2010*

*Milestone: Ten advanced generation interspecific derivatives screened for *Helicoverpa*, AB and BGM in target locations in India (NM/HCS/SP/PMG) 2012*

**Evaluation of interspecific derivatives for resistance to *Helicoverpa armigera*:** We evaluated six progenies from the interspecific derivatives for resistance to pod borer, *H. armigera* along with five resistant and



susceptible checks from the cultivated chickpea under natural infestation in the field, and detached leaf assay in the laboratory. In detached leaf assay, leaf damage rating was 4.0 in line 211-1 compared to 3.0 in ICC 506, 4.7 in ICC 37, and 8.0 in line 117-10. At the vegetative stage, leaf damage rating in line 116-4 was 2.5 compared to 4.5 in line 320-7 and 5.5 in ICC 3137. At maturity, pod damage was 5.8% in line 117-10, and 4.3% in line 321-3 compared to 25.3% pod damage in ICC 3137 (control).

HC Sharma and N Mallikarjuna

Disease/insect resistance in wild *Cicer* species: Two hundred and seventeen wild chickpea crosses and interspecific derivatives were screened for BGM resistance in controlled environment at ICRISAT, Patancheru. Using cut twig screening technique, 110 lines of five wild *Cicer* spp. [*C. bijugum* (1), *C. echinospermum* (48), *C. reticulatum* (47), *C. judaicum* (3) and *C. cuneatum* (11)] were screened for AB under controlled environment. Of the 110 derivatives evaluated, 19 were resistant (3.1-5.0 rating on 1-9 scale) to AB. Ten derivatives of *C. echinospermum* were found resistant followed by *C. reticulatum* (7) and one each of *C. bijugum* and *C. judaicum*. *Cicer reticulatum* was crossed with cultivated chickpea and the interspecific derivatives at F<sub>2</sub> and F<sub>3</sub> generation were screened for Botrytis gray mold using detached leaf technique developed for chickpea. Screening results showed that the resistance present in the wild species for BGM was monogenic and recessive.

Fifty-nine lines from advanced generation interspecific derivatives generated from *Cicer reticulatum* accessions were screened for *Helicoverpa armigera* resistance under unprotected field conditions. Seven lines had less than 10% damage due to *H. armigera*. Lines with less than 10% damage were selected for further screening. Crosses were made using *C. reticulatum* accessions, that have shown resistance to Botrytis gray mold, Ascochyta blight and *H. armigera*.

N Mallikarjuna, HC Sharma, S Pande and PM Gaur

*Milestone: Wild relatives with diverse mechanisms of resistance to Helicoverpa, AB and BGM identified (HCS/SP) 2009*

Several screening techniques such as whole plant screening (WPST), and cut twig screening technique (CTST) have been developed and standardized at ICRISAT-Patancheru. Resistance screening using cut twig screening technique correlates with greenhouse screening. This quick, reliable, and repeatable technique is useful in screening segregating lines derived from wide hybridization, since whole plant can then be used to screen for other target traits and seed production. Optimum conditions for CTST such as optimum temperature, relative humidity, and photoperiod for AB and BGM were identified. Tender shoots of chickpea plants were cut from actively growing chickpea plant (30 - 60 days after sowing) with a sharp edged blade in the evening and planted into sterilized moist coarse sand-vermiculite medium in trays. Trays were kept in the controlled environment facility, allowed to acclimatize for 12-24 h, and inoculated following standardized procedures. The disease score was recorded on 1 - 9 rating scale. Using this technique, 23 wild *Cicer* lines from seven wild species, *C. pinnatifidum*, *C. judaicum*, *C. bijugum*, *C. reticulatum*, *C. microphyllum*, *C. chrossanicum*, *C. cuneatum*, and five lines from cultivated species, *C. arietinum* were screened for AB under controlled environment. Of the 23 wild *Cicer* lines evaluated, only four lines from *C. judaicum* (PI 572536, PI 568217, PI 599097, IG 70032) were found to be moderately resistant (3.1-5.0 rating on 1-9 scale) to AB.

S Pande and HC Sharma

**Evaluation of annual wild relatives of chickpea for resistance to *Helicoverpa armigera*:** We evaluated nine accessions of wild relatives of chickpea, along with resistant (ICC 506) and susceptible (ICCC 37, ICC 3137, and L 550) checks for resistance to the pod borer, *H. armigera* under greenhouse and field conditions using detached leaf assay. There were three replications in a completely randomized design. In the plants raised under greenhouse conditions, leaf damage rating in IG 70012, IG 70018 and IG 92933 was <2.6 compared to 4.6 in control L 550. The larvae weighed <1.0 mg when reared on the leaves of IG 69979, IG 70012, IG 70018, IG 70022, and IG 70032 as compared to 2.59 mg on ICC 3137 and 1.99 mg on ICC 506. In the plants raised in the field, leaf damage rating was lower (4.8 – 5.0) on IG 599076, IG 69979 and IG 72933 compared to 3.8 on ICC 506 and 7.0 on Annigeri. Larval weights were 2.22 to 2.92 mg in larvae reared on the leaves of IG 599076, IG 70006, IG 70022 and IG 70032 compared to 3.28 mg on ICC 506, and 5.43 mg on Annigeri. The results suggested that antibiosis is an important mechanism of resistance to *H. armigera* in wild relatives of chickpea.

In another experiment, 20 accessions of wild relatives were tested along with resistant (ICC 506) and susceptible (ICC 3137) checks under greenhouse and field conditions. The terminal branches were infested with 10 neonate larvae of *H. armigera* using detached leaf assay. At five days after initiating the experiment, the larval weights were lower on PI 51063, PI 568217, PI 599046, PI 599066, PI 599077, PI 59078, PI 599097, and PI 599105

(<2.11 mg per larva) as compared to 4.94 mg on ICC 506, and 5.93 mg on ICC 3137. These accessions also had low leaf feeding and *H. armigera* larvae under field conditions.

**Evaluation of perennial wild chickpeas for resistance to *Helicoverpa armigera*:** Sixteen accessions of perennial wild relatives of chickpea, along with the local perennial wild chickpea, *Cicer microphyllum*, were also tested for resistance to *H. armigera* at the flowering stage at the Regional Research Station, Himachal Agricultural University, Kukumseri, Himachal Pradesh, India. The terminal branches were infested with 10 neonate larvae of *H. armigera* using detached leaf assay. At five days after initiating the experiment, the larval weights ranged from 0.48 to 1.24 mg on the wild accessions compared to 5.93 mg normally attained on the cultivated chickpea genotype, ICC 3137. Weight gain by the third instar larvae was lower (2.4 to 8.6 mg) on PI 353625, PI 532928, PI 599080, PI 599082, PI 599083, PI 899089, and PI 593719 as compared to 32.2 mg on the wild local, *C. microphyllum*.

HC Sharma, Dorin Gupta and SL Clement

*MTP output target 2007 6.1.1 CP: 50 transgenic events of chickpea with Bt genes developed and screened in contained greenhouse (KKS/HCS/PMG)*

*Output target CP 6A.4: Promising transgenic events of chickpea with proven resistance to Helicoverpa available for commercialization and introgression in locally adapted germplasm*

**Activity CP 6A.4.1: Develop transgenic events of chickpea for resistance to *Helicoverpa armigera* and evaluate their performance under contained greenhouse and field conditions**

In our ongoing efforts to develop transgenic plants of chickpea engineered for resistance to *Helicoverpa armigera*, several *Bt* genes have been used through *Agrobacterium tumefaciens*-mediated genetic transformation of popular chickpea cultivar C 235 using the axillary meristems as the explants. For efficient expression of *cryIAC* gene in chickpea, binary vectors with different promoters were used. Chickpea transgenics are being developed using dicot codon optimized *Bt cryIAC* gene constructs under the influence of Ubiquitin (pPZP200) and CaMV35S promoters (PRD 400). About 35 independent transgenic events have been produced and transferred to the greenhouse. Molecular characterization of these plants is underway.

Chickpea transgenics carrying the *Bt cryIAb* or *cryIAC* genes independently are under evaluation for resistance to *Helicoverpa armigera* in the contained greenhouse. A total of 55 independent transgenic events have been produced and advanced to T<sub>1</sub> generation. The transgenic plants have been analyzed for integration of transgene by PCR, and also characterized for expression of the *Bt* genes using ELISA. Twenty-one events with 8 replicates of each in T<sub>1</sub> generation were sown in greenhouse and evaluated using ELISA and PCR. Preliminary bioassay for resistance to *Helicoverpa* using the leaf is in progress.

Besides, codon-optimized synthetic *cryIAC* genes for its optimal expression in chickpea using codon usage frequencies derived from the gene sequences available for various legumes (such as chickpea, pigeonpea, soybean, pea and *Medicago*) have been carried out for eventual production of events resistant to insects. A *cryIAC* gene sequence with enhanced GC content has been modified to eliminate potential polyadenylation termination signals. The modified sequence driven by both Ubiquitin and CaMV35S promoters are being sub cloned into cloning/expression vectors to enhance the expression of *Bt cry* toxins in legume plants.

KK Sharma and P Bhatnagar-Mathur

**Evaluation of putative transgenic chickpea plants for resistance to pod borer, *Helicoverpa armigera*:** A total of 156 *cryIAb* (from 23 events) and 97 *cryIAC* (from 14 events) transformed T<sub>1</sub> chickpea plants along with non-transformed counterpart C 235, and *Bt* and non-*Bt* cottons (Mech 184) as controls, were evaluated for resistance to pod borer, *Helicoverpa armigera* under laboratory conditions. The terminal branches from each plant on single replication were bioassayed for resistance to *H. armigera* using detached leaf assay.

Observations were recorded on leaf damage on a 1 to 9 scale (1 = <10% leaf area damaged and 9 = >80% leaf area damaged), larval survival and larval weights after five days of feeding. In the *cryIAb* transformed chickpeas, the damage rating, larval survival, and larval weight varied between 1.0 to 9.0, 10 to 100%, and 0.45 to 27.1 mg larva<sup>-1</sup>, respectively, while on non-transformed genotype, C 235, the leaf damage rating was 6.4, larval survival 64.3%, and larval weight 10.9 mg larva<sup>-1</sup>. In *Bt*-transgenic versus non-transgenic cottons, the leaf damage rating was 2.8 versus 7.2, larval survival, 32.0 versus 74.0%, and the larval weight 0.76 versus 1.97 mg larva<sup>-1</sup>. In the *cryIAC* transformed chickpeas, the leaf damage rating, larval survival, and larval weights varied between 3.0 to 9.0, 40 to 100%, and 1.94 to 15.40 mg larva<sup>-1</sup>, respectively. Based on the preliminary bioassay

results, the plants having low leaf damage, lower survival, and less weight gain were selected for retesting. A total of 15 *cryIAb* (from 10 events) and 9 *cryIAc* (from 5 events) plants were selected, and bioassayed with neonate *H. armigera* larvae along with non-transformed C 235, and *Bt* and non-*Bt* cotton (Mech 184) as controls, using detached leaf bioassay. There were five replications in a randomized complete design. Observations were recorded on leaf damage, larval survival and larval weights after five days. Although there were significant differences in leaf damage ratings and larval weights, the differences in larval survival were non-significant. The leaf damage rating in the *Bt*-transformed chickpeas varied between 3.6 to 8.4, larval survival from 74 to 94%, and larval weights from 3.26 to 7.27 mg larva<sup>-1</sup> compared to 1.2 leaf damage rating, 8% larval survival, and 0.25 mg larval weight on *Bt* cotton as against 7.2 leaf damage rating, 66% larval survival, and 0.51 mg larval weight on the non-transformed cotton. The leaves from these plants were also subjected to ELISA test (Agdia ELISA kit). The results indicated that there was no *Bt* protein expressed in any of the *cryIAb* or *cryIAc* transformed chickpeas.

HC Sharma, MK Dhillon and KK Sharma

*Milestone: At least 8 promising Bt transgenic events of chickpea identified and insect resistance characterized under contained greenhouse conditions (KKS/HCS/PMG) 2009*

Work on the identification of promising transgenic events ongoing and linked to the milestone of 2008.

*Milestone: Three promising Bt transgenic events of chickpea identified and insect resistance characterized under contained field conditions (KKS/HCS/PMG) 2010*

Work will be initiated following the identification of 8 promising transgenic events under contained greenhouse conditions.

*Milestone: One or two transgenic events of chickpea used for introgression into locally adapted genotypes and the progeny characterized and evaluated (KKS/HCS/PMG) 2011*

Activities not initiated yet.

KK Sharma and P Bhatnagar-Mathur

## **Pigeonpea**

*Internal output target PP 6A.1: About 5-6 pigeonpea varieties with stable resistance to Fusarium wilt, sterility mosaic and Helicoverpa made available to NARS*

**Activity PP 6A.1.1: About 15 new genetically diverse germplasm sources/breeding lines resistant to wilt and sterility mosaic diseases identified**

*Milestone: 25-30 pigeonpea lines tested across locations for their stability to wilt and sterility mosaic resistance in India (SP) Annual*

**Identification of stable sources of resistance to Fusarium wilt and sterility mosaic:** Pigeonpea lines having combined resistance to wilt and sterility mosaic (SM) identified at ICRISAT-Patancheru were evaluated for resistance to both these diseases at different locations in India through pigeonpea wilt and sterility mosaic disease nursery (PWSMDN) to identify stable and broad based resistance to wilt and SM. Thirty two entries comprising 28 wilt and SM resistant lines, two susceptible checks from ICRISAT and another two susceptible checks (one for each disease) from the test location, were evaluated at 18 locations in India (Akola, Badnapur, Bangalore, Berhampore, Coimbatore, Dholi, Faizabad, Gulberga, Hazaribag, ICRISAT-Patancheru, Kanpur, Khargone, Rahuri, Raipur, Sehore, Pudukottai, Vadodara, and Varanasi) for both these diseases during 2006/07 season. In most of the locations the nursery was planted in wilt sick plot and each plant was inoculated with SM pigeonpea leaves using leaf staple technique at two leaf stage wherever possible, or SM infested twigs were spread on the plants of the nursery at seedling stage for SM development. Data on wilt and SM were recorded twice, at flowering and at maturity stages of the crop.

Data was received only from 8 locations. Susceptible check, ICP 2376 had high (>70%) wilt incidence in Akola, ICRISAT, Dholi, Khargoan, Rahuri, and Vadodara; whereas it was low (<12.5%) at Bangalore and Raipur. Incidence of wilt in local check was around 60% in Akola, Bangalore, ICRISAT, Dholi, Khargoan, and Rahuri, but was very low in Raipur (9%) and Vadodara (1.1%). The differential reaction of both susceptible checks

(local as well as ICP 2376) at Vadodara indicated the possible presence/existence of races/pathotypes in the wilt pathogen. Of the 28 entries tested, 20 entries at Akola, 25 at Bangalore, 17 at Dholi, 27 at ICRISAT, 15 at Khargone, 24 at Raipur, 9 at Rahuri and 13 at Vadodara were resistant to wilt (< 10% wilt). Data on SM was recorded only in five locations (Bangalore, Dholi, ICRISAT, Rahuri and Vamban). At Sehore, incidence of Phytophthora was high but wilt and SM were not observed. Both SM susceptible checks had high SM incidence at all these locations. All the 28 entries at ICRISAT, 5 entries at Dholi, 15 entries at Rahuri, and 10 entries at Vamban were found resistant (<10% SM incidence). No line was resistant to SM at Bangalore.

S Pande and NARS Collaborators

*Milestone: About 100 germplasm/advanced breeding lines screened for wilt and sterility mosaic disease resistance using different isolates and characterized for agronomic traits (SP/PLK/RKS/KBS/HDU) 2009*

**Fusarium wilt and SM resistance in advanced breeding lines:** Fifty-one lines (47 lines from advanced lines and selections from breeders material in 2004/05 and 2005-06, four selections from IIPR, Kanpur in 2005/06) were evaluated for combined resistance to FW and SM under artificial epiphytotic conditions during 2006-07 at ICRISAT-Patancheru. FW susceptible cultivar showed 100% disease incidence and SM susceptible cultivar showed >90% disease incidence. Of the 47 advanced selections, 45 lines had a combined resistance (< 10% incidence) to both FW and SM. Four lines (ICPL 20116, ICPL 20127, ICPL 20136, and ICPL 20138) were asymptomatic to both FW and SM. However, 8 lines (ICPL 20094, ICPL 20100, ICPL 20102, ICPL 20113, ICPL 20116, ICPL 20127, ICPL 20136 and ICPL 20138) were asymptomatic to FW, and 22 lines to SM. Among the four advanced wilt and SM promising selections (KPL 96053, MAL 13, MAL 23 and MA-S-DEO-74) from IIPR Kanpur, all were resistant (<10%) to both FW and SM. Three lines were found asymptomatic to SM.

S Pande and KB Saxena

**Fusarium wilt and SM reaction of Helicoverpa resistant lines:** Thirty Helicoverpa-resistant lines were evaluated for combined resistance to FW and SM under artificial epiphytotic conditions using the standard field screening technique. Among these lines, neither combined resistance to both diseases nor to FW alone was observed in any of these lines. However, six lines (ICP 7035, ICPL 85063, ICPL 269, ICP 8094, ICP 3615, and ICP 13216) were resistant to SM (< 10% incidence).

S Pande and HC Sharma

**ICAR-ICRISAT collaborative research on pigeonpea Fusarium wilt and SM:** Under the ICAR-ICRISAT collaboration, 96 entries (57 entries from national nursery for AVT and 30 entries from national nursery for resistance to wilt, and 9 entries from national nursery for resistance to SM) from IIPR, Kanpur, were evaluated for FW and SM resistance under artificial epiphytotic conditions following standard field screening technique. Combined resistance to FW and SM was found in four lines (BDN 2, IPA 8 F, BDN 2029 and AKT 221030) in the AVT. Three entries (IPA 16 F, IPA 8 F and BRG 26) were asymptomatic to SM. Among the entries in the national nursery for resistance to wilt, two entries, IPA 204 and IPA 16 F had a combined resistance to FW and SM. Nine entries were asymptomatic to SM and 7 were resistant (<10%). Two entries (IPA 204 and IPA 16 F) were found resistant to FW.

S Pande and NARS Collaborators

**Collection, purification and maintenance of virulence of isolates of Fusarium udum:** Twenty isolates of Fusarium udum collected from 9 locations in 6 states in India were purified for maintenance of virulence. Pathogenicity test was done using a common susceptible cultivar ICP 2376 following root dip technique under greenhouse conditions at ICRISAT-Patancheru. Koch's postulates were proved and isolations were made from freshly wilted seedlings and incubated at 25<sup>0</sup>C in the incubators for seven days. Pure cultures were selected and single spore isolates obtained following standardized mycological techniques.

**Standardization of protocols for pathogenic and molecular characterization of Fusarium udum isolates:** A total of 20 isolates collected from 9 locations in 6 states in India till 2007 were evaluated for pathogenic variation of Fusarium udum in greenhouse. Root dip technique was standardized and followed for inoculation. In this technique, pigeonpea seedlings were raised in sand in polythene bags for seven days. Pure culture of the F. udum was multiplied on potato dextrose broth for 7 days. After seven days, seedlings were root inoculated by dipping the roots in the inoculum and transplanted in pre-irrigated pots (12.5 cm) @ five seedlings per pot and replicated thrice. Seedlings were observed for 40 days for wilt development. Initial and final wilt incidence in each pot and mortality due to wilt were recorded at weekly intervals. Data analysis is in progress. All the

twenty isolates of *F. udum* will also be studied for genetic variation using Amplified Fragment Length Polymorphism (AFLP).

S Pande, M Sharma, R Varshney and D Hoisington

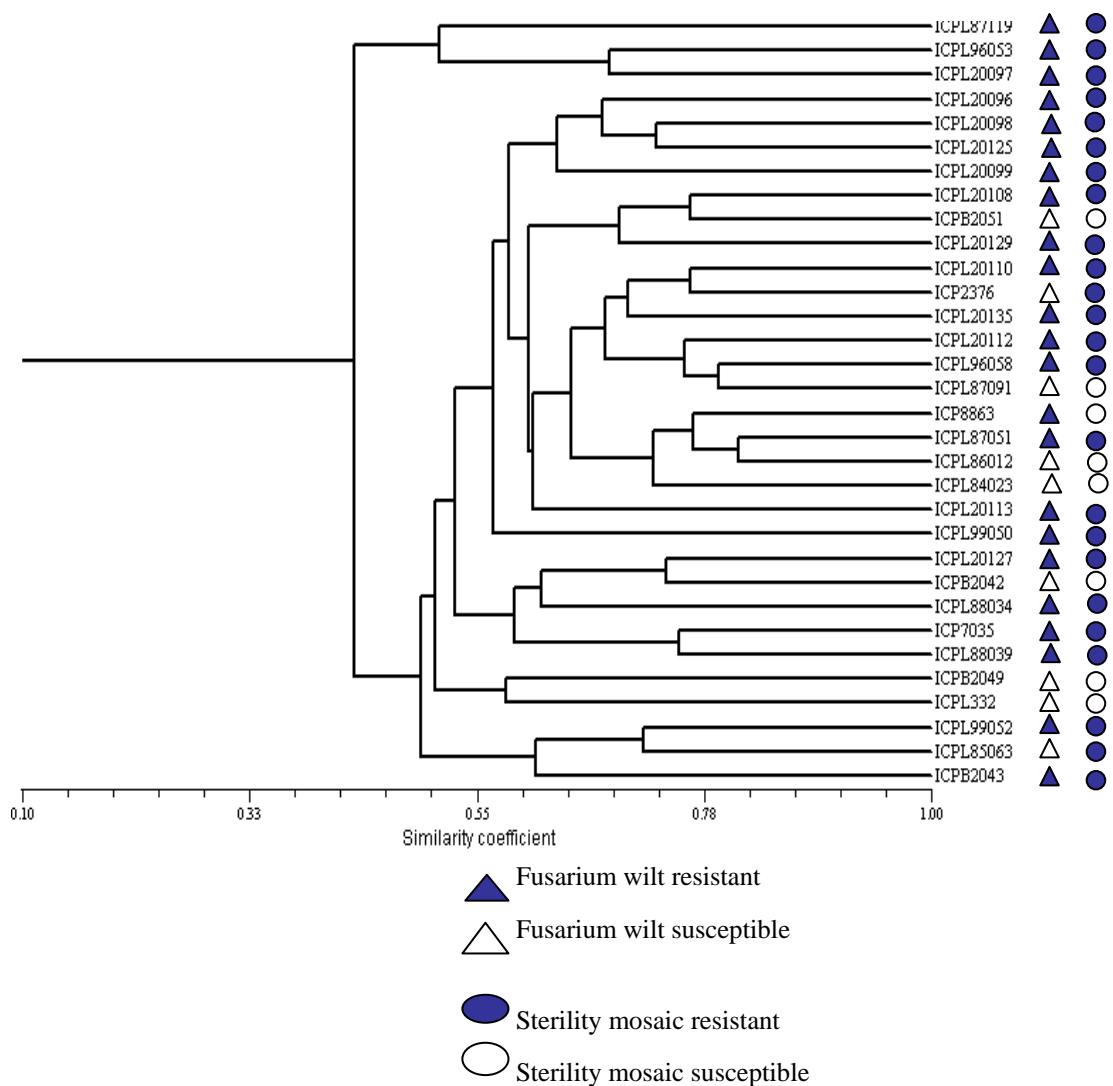
*Milestone: Molecular characterization of wilt/sterility mosaic resistant and susceptible germplasm/breeding lines for developing mapping populations with diverse genetic background (RKV/RKS/KBS/DAH) 2009*

**Molecular characterization of wilt/sterility mosaic resistant and susceptible germplasm:** A set of 32 genotypes (twenty resistant and five susceptible to both Fusarium wilt and sterility mosaic, two resistant to sterility mosaic, and one resistant to Fusarium wilt) was selected. The selected 32 genotypes were screened for polymorphism with the existing set of highly polymorphic 30 SSR markers at ICRISAT. Out of these 30 SSR markers, only 23 markers displayed polymorphism in the germplasm examined. These markers revealed 2 to 4 alleles (average 2.6) with the PIC (polymorphism information content) value in the range of 0.12 to 0.65 (average 0.44) per marker. Genetic relationships among different genotypes are shown in Figure 4. Based on genotypic and phenotypic data, we have selected five crosses, from which one cross is for FW (ICPB 2049 × ICPL 99050), two are for SM (ICPL 20097 × ICP 8863 and ICP 7035 × ICPL 332), and two crosses segregate for both FW and SM (ICPL 20096 × ICPL 332 and ICPL 87119 × ICPL 87091).

**Activity PP 6A.1.2: Genetically diverse germplasm/breeding lines with resistance to *Helicoverpa* identified**

*Milestone: About 100 germplasm/advanced breeding lines screened for resistance to *Helicoverpa* under field and/or laboratory conditions (HCS/KBS/HDU) 2009*

**Advanced pigeonpea-breeding lines evaluated for resistance to *Helicoverpa armigera*:** We evaluated selections from mini-core collection and purple pod lines of pigeonpea germplasm (34 lines) along with resistant ICPL 332, and susceptible checks, ICPL 87 and ICPL 87119 for resistance to *H. armigera*. There were three replications in a randomized complete block design. Eight lines showed a damage rating (mostly of the second flush) (DR) (1 = <10% pods damaged, and 9 = >80% pods damaged) of <5.0 compared to a DR of 5.5 in ICPL 332 and 9.0 in ICPL 87. Recovery resistance score (1 = good, and 5 = poor) of these lines was 4.0 to 5.5 compared to 5.0 of ICPL 332, 4.5 of ICPL 87119 and 9.0 of ICPL 87. The accessions ICP 11160, ICP 12510, ICP 12510-1 and ICP 8688 showed a grain yield potential of 1507 to 2082 kg ha<sup>-1</sup> compared to 775 of ICPL 332 and 83 kg of ICPL 87 under unprotected conditions.



**Figure 4: Genetic relationships among 32 genotypes based on the analyses of 23 SSR markers**

R Varshney, Rachit Saxena and KB Saxena

**Relative susceptibility of white seeded pigeonpea lines to pod borer, *Helicoverpa armigera*:** White seeded pigeonpea grain fetches a premium price in certain locations, and therefore, we evaluated 21 white seeded lines of pigeonpea for resistance to *H. armigera*. There were three replications in a randomized complete block design. Data were recorded on pod borer damage on a 1 – 9 rating scale, recovery resistance, and grain yield. The first flush was completely damaged. In the second flush, ICP 6682, ICP 7043, ICP 7044, ICP 7529, ICP 7534, ICP 7613 and ICP 8674 showed moderate levels of pod damage and recovery resistance (scores 4 to 5). Of these, ICP 7043, ICP 7044, ICP 7613 and ICP 8674 also showed good yield potential (1033 to 1430 kg ha<sup>-1</sup>) compared to 350 kg of ENT 11 and 80 kg of ICP 7734.

HC Sharma

**Relative performance of improved lines for resistance to pod borer, *Helicoverpa armigera*:** In another trial, we evaluated 12 newly developed varieties of pigeonpea along with ICPL 332, ICPL 87119 and ICPL 87 for resistance to *H. armigera* under protected and unprotected conditions. Data were recorded on pod damage, recovery resistance and grain yield. Pod borer damage in this trial was quite high (DR 6.7 to 9.0). Overall resistance and recovery resistance scores were 5.0 to 6.0 in ENT 11, ICP 7035, ICPL 332, and ICPL 87119. Grain yield of ICPL 20058, ICP 4985-4, ICP 7035 and ICPL 87119 was quite high (1067 to 1253 kg ha<sup>-1</sup>) compared to 376 kg of ICPL 87 and 847 kg of ICPL 332. Promising pigeonpea lines (ICPL 332 WR, ENT 11,

and ICP 7035) were tested on farmers' fields for assessing their usefulness in pest management under farmers field conditions.

HC Sharma and KB Saxena

### **Activities PP 6A.1.3: Advanced generation interspecific derivatives with resistance to *Helicoverpa* using wild species from different gene pools developed**

*Milestone: Physico-chemical mechanisms of resistance to Helicoverpa in wild relatives of pigeonpea identified for use in crop improvement (HCS) 2009*

**Physico-chemical mechanisms of resistance to *Helicoverpa* in pigeonpea:** Fifteen morphologically diverse lines of pigeonpea were studied for their interaction with *H. armigera* along with the resistant (ICPL 332) and susceptible (ICPL 87 and ICPL 87119) checks in the field. The material was planted in 4 row plots, 2m long. There were three replications in a RCBD. Data were recorded on oviposition, larval density and pod damage by *H. armigera* and recovery resistance on 1 – 9 scale as described above. There were 4.0 to 9.0 eggs per 5 inflorescences of ICP 11947, ICP 5529, ICP 11975, ICP 9880, and ICPL 332 compared to 25.3 eggs in inflorescences of ICP 12476; while the larval numbers were lower (11.3 to 15.3 larvae) on ICP 9879, ICP 12476, ICP 9879, ICP 12942, ICP 9879, ICP 11975, ICP 9880, ICPL 332 across five observation dates. Although the first flush was completely damaged by pod borer, the genotypes ICP 12476, ICP 12492, and ICP 8102 showed moderate levels of recovery resistance (RR 4.0 to 6.0) compared to ICPL 87 (RR 8.7). Of these, ICP 8102, and ICPL 87119 yielded 1499 and 2411 kg ha<sup>-1</sup> (respectively) compared to 349 kg of ICPL 87. The mechanisms of resistance in these pigeonpea genotypes are being studied in greater detail to identify morphological and biochemical markers for use in crop improvement.

**Flavonoid profile of wild relatives of pigeonpea in relation to expression of resistance to *Helicoverpa armigera*:** Fifteen genetically diverse lines of pigeonpea, with different levels of resistance to *H. armigera*, were characterized for their flavonoid profiles, extracted in polar solvents, using reverse phase High Performance Liquid Chromatography (HPLC) with C<sub>18</sub> column. Data analysis is in progress.

HC Sharma

*Milestone: Gene introgression from wild *Cajanus* into cultivated pigeonpea studied (NM/HDU/KBS) 2010*

*Milestone: Ten interspecific derivatives from different *Cajanus* species belonging to different gene pools with resistance to *Helicoverpa* identified for use in pigeonpea improvement (NM/HCS/HDU) 2011*

**Evaluation of interspecific derivatives of pigeonpea for resistance to *Helicoverpa armigera*:** Twelve interspecific derivatives from wild relatives of pigeonpea were evaluated for resistance to pod borer, *H. armigera* along with the resistant, ICPL 332, and susceptible, ICPL 87119 checks under field conditions. There were three replications in a RCBD. Data were recorded on pod damage, recovery resistance and grain yield. Pod borer damage in the first flush was very high (DR 8 – 9). However, (Pant A-2 x *C. albicans*) 9-2-1, (Pant A-2 x *C. lanceolatus*) 1-2, (Prabhat x *C. scarabaeoides*) 3-2-2-1 and (Prabhat x *C. scarabaeoides*) 12-2-2 showed moderate levels of recovery resistance, and grain yield potential comparable to ICPL 332. In another trial, 40 individual plant sections were evaluated for pod borer resistance along with five resistant and susceptible checks. Sixteen lines were selected from this set for further testing that had pod borer damage and yield potential comparable to ICPL 332. In another trial, we evaluated 74 F<sub>7</sub> progenies of ICPW 94 x ICP 28 cross for agronomic traits and resistance to pod borer, *H. armigera*. Data recording is in progress. The 107 biparental progenies of the same cross are being evaluated for resistance to *H. armigera* under natural infestation in the field.

HC Sharma, HD Upadhyaya and N Mallikarjuna

**Crosses with secondary gene pool species:** Crosses were made between pigeonpea cultivars and *Cajanus scarabaeoides* (ICPW 94), which produced 130 mature seeds. F<sub>2</sub> and BC<sub>1</sub> hybrids were screened for *H. armigera* under unprotected field conditions and lines with low damage were identified. Some of the lines had higher seed weight than the controls. Some of the lines have shown SMD resistance under laboratory bioassays. Further studies are in progress. Crosses between pigeonpea and *C. lineatus* ICPW 41 gave rise to both immature and mature seeds. Variation in growth habit was noticed in the F<sub>1</sub> progeny.

A total of 1,010 advanced generation interspecific derivatives between *C. cajan* and *C. acutifolius* were selected for *H. armigera* resistance under unprotected field conditions. Ten percent of the derivatives had 0-10 % pod

damage. Twenty percent of the plants had 11 - 20% damage. Due to continuous selection for low damage, less than 20% of the plants showed 50% or more damage. In some of the selected plants damage due to *H. armigera* was less than 5%, but damage due to pod fly and bruchids was high (10 - 30%). Some of the lines showed higher seed weight than both the parents. Such lines have been selected for further screening.

**Crosses with tertiary gene pool species:** BC<sub>4</sub>F<sub>2</sub> lines derived from *C. platycarpus* x *C. cajan* were evaluated for various morphological traits, and showed some differences in plant growth habit. Line BC<sub>4</sub>F<sub>2</sub>-A 2-1 showed dwarf growth habit in comparison to spreading and semi-spreading growth habit in the rest of the 25 lines. It was observed that there were significant differences between the lines for pod length and plant height. Differences (15 - 45%) were observed for *H. armigera* damage.

N Mallikarjuna, HC Sharma, F Waliyar and KB Saxena

*Output target PP 6A.2: Promising transgenic events of pigeonpea with proven resistance to Helicoverpa available for commercialization and introgression in locally adapted germplasm*

**Activity PP 6A.2.1: Develop transgenic events of pigeonpea for resistance to *Helicoverpa armigera* and evaluate their performance under contained greenhouse and field conditions**

*Milestone: 80 transgenic events of pigeonpea with Bt genes developed and screened in contained greenhouse (KKS/HCS/PBM/KBS) 2008*

In our ongoing efforts to develop transgenic plants of pigeonpea with *Bt* genes, a focused approach has been initiated to engineer resistance to *H. armigera* in pigeonpea by using *cryIAc* gene through *Agrobacterium tumefaciens*-mediated genetic transformation of a popular pigeonpea cultivar, ICPL 88039. For efficient expression of *cryIAc* gene in pigeonpea, binary vectors have been constructed with different promoters. Pigeonpea transgenics were developed using dicot codon optimized *Bt cryIAc* gene constructs under the influence of Ubiquitin (pPZP200) and CaMV35S promoters (PRD 400) using seedling leaf petiole as the explant. A total of 80 independent transgenic events have been produced and transferred to contained greenhouse for further evaluation. The transgenic plants have been analyzed for the transgenes by PCR, and also characterized for expression of the *Bt* gene using ELISA. Further preliminary evaluation of these events for resistance to *Helicoverpa* using bioassays is planned. In parallel, about 30 marker free pigeonpea transgenics using the binary vector pPZP200 that consists of *cryIAc* gene driven by CaMV35S and Ubiquitin promoters independently, are being produced and are in different stages of development.

Although, there has been a considerable reduction in larval weights on pods of transgenic plants in our earlier reports, the unknown factors that reduce the efficient expression of the insecticidal gene in legumes are being probed further. We have initiated the development of a codon-optimized synthetic *cryIAc* gene for its optimal expression in pigeonpea using codon usage frequencies derived from the gene sequences available for various legumes (such as chickpea, pigeonpea, soybean, pea and *Medicago*). These genes have been modified for the GC content according to the legume genomes, thus, removing the AT-rich regions that are typical of *Bt cry* genes. Also, other mRNA destabilizing and hairpin forming structural sequences have been removed. The construct carrying these codon optimized *Bt* genes (based on legumes codon usage) driven by both Ubiquitin and CaMV35S promoters, are being subcloned into cloning/expression vectors to enhance the expression of *Bt cry* toxins in legume plants.

KK Sharma, P Bhatngar-Mathur and HC Sharma

*Milestone: Three promising Bt-transgenic events of pigeonpea identified and insect resistance characterized under contained field conditions (KKS/HCS/KBS) 2009*

The primary transgenic events have been advanced to T1 generation and are being tested at the molecular level for testing in insect bioassays.

*Milestone: One to two Bt-transgenic events of pigeonpea used for introgression into locally adapted genotypes (KKS/HCS/KML) 2010*

The activity will commence following the identification of promising events in the milestone for the year 2009.



*Milestone: Commercialization package for the introduction of pigeonpea with transgenic resistance to Helicoverpa armigera available for deployment (KKS/HCS/KML) 2011*

The activities have not been initiated at this time.

*Output Target PP 6A.3: Twenty medium-long duration vegetable type pigeonpea germplasm/breeding lines made available*

**Activity PP 6A.3.1: Evaluation and selection of large podded medium – long duration germplasm and breeding lines for use as vegetable**

Milestone: Research Bulletin on vegetable pigeonpea published (KBS) 2007

Deferred to 2008.

KB Saxena

*Milestone: At least 5-10 large seeded high-yielding vegetable type breeding lines and germplasm identified (RKS/KBS/HDU) 2008*

*Milestone: Genetically diverse large seeded vegetable type 10-15 breeding populations for further selection developed (KBS/RKS) 2011*

Fifteen medium-duration vegetable type pigeonpea breeding lines were received from Gujarat. These lines were screened for wilt and sterility mosaic diseases in the disease screening nursery. Of these, only six lines viz., SIPS 5, SIPS 6, SIPS 7, SIPS 9, SIPS 18 and SGBS 4 were resistant to sterility mosaic, while three lines SIPS 5, SIPS 15 and SGBS 6 were resistant to wilt. Only one line, SIPS 5, was resistant to both wilt and sterility mosaic diseases. The resistant lines were selfed to obtain pure seed, and were also used in devising new hybrids with ICPA 2043. These lines are being further evaluated for disease resistance and yield potential at ICRISAT-Patancheru.

RK Srivastava, KB Saxena and HD Upadhyaya

## Sorghum

2007 6.1.2 SO: Major grain mold pathogens in sorghum growing states in India identified and their distribution in relation to weather factors characterized

Major grain mold pathogens. A large number of fungi, both saprophytic and pathogenic have been reported to be associated with the sorghum grain mold complex. In order to find genetic resistance in sorghum lines it is important that fungi that are truly pathogenic and actively involved in host-pathogen interaction are identified and their relative frequency determined. Through an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002–2004, several pathogens consistently associated with grain mold were identified. The analysis of SGMVN data from these locations revealed that several species of *Fusarium*, *Curvularia lunata* and *Alternaria alternata* were generally more frequent and highly consistent than other fungi. Of more than 900 isolates of *Fusarium* obtained from grain samples from these locations, six species of *Fusarium* (*F. proliferatum*, *F. verticillioides*, *F. thapsinum*, *F. andiyazi*, *F. nygamai* and *F. sacchari*) were identified. Strains of some of these *Fusarium* species are known to produce fumonisins, a kind of mycotoxin that is hazardous to health.

Influence of weather variables on occurrence of pathogenic mold fungi. We studied the influence of weather variables, temperature (T) and relative humidity (RH), on the occurrence of major pathogenic fungi, such as *Fusarium* spp., *Curvularia lunata*, *Alternaria alternata* and *Phoma sorghina* associated with sorghum grain mold in India. The T and RH data, and frequency of mold fungi collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Variability Nursery (SGMVN) conducted at five locations (Akola, Parbhani, Palem, Patancheru and Surat) during three rainy seasons 2002–2004 was used for this study. Since minimum temperature (Tmin) and maximum temperature (Tmax) during flowering to physiological maturity are most critical for mold development, distribution of pathogenic fungi in relation to these weather variables was studied. It appears that Tmin 18–20°C and RHmax around 80% favored *Curvularia* at Akola and Surat and higher RHmax (around 90%) and almost same Tmin favored *Alternaria* and *Phoma* at Patancheru. However high Tmin seems to favor *Fusarium* as the fungus was predominant at Parbhani having Tmin around 22°C.

RP Thakur and Rajan Sharma

Association of mycotoxin-producing *Fusarium* spp. with sorghum grain mold in field and/or in storage is important because mycotoxin-contaminated food and feed create health hazard for humans and cattle. Forty-seven cultures of *Fusarium* spp., obtained from molded sorghum panicles at ICRISAT were studied for their speciation and fumonisins (FB1 & FB2) production potential. A preliminary morphological study at Medical Research Council, South Africa, revealed 17 of these cultures as potential fumonisin producers and subsequently 14 of these were confirmed through a mating type study at Kansas State University, USA. These cultures were tentatively identified into six different species: *F. proliferatum*, *F. thapsinum*, *F. verticillioides*, *F. sacchari*, *F. nygamai* and *F. andiyazi*. In a collaborative study with Iowa State University, Ames, 12 of these isolates were assayed for fumonisins FB1 & FB2 production using high performance liquid chromatography. Of these, *F. proliferatum* isolates produced higher FB1 (2.318–7.560 µg/g) and FB2 (0–8.478 µg/g) than other isolates. Insignificant amount of FB2 was detected in isolates of *F. sacchari*, *F. andiyazi* and *F. nygamai* and in some isolates of *F. thapsinum*. FB1 detected in potato dextrose-agar (PDA) culture of *F. proliferatum* was high (10.850 µg g<sup>-1</sup>) compared to that of *F. verticillioides* with no FB1 detected. These results on species identification and fumonisins production by *Fusarium* spp. involved in sorghum grain mold complex in India are an important addition to the available information on fumonisins production by *Fusarium* species. Based on colony growth characteristics on PDA, 682 cultures of *Fusarium* collected from five locations (Akola, Parbhani, Palem, Patancheru and Surat) in India were tentatively classified into six species with varying frequencies. The mean frequency of *F. proliferatum* across locations was 48%, followed by 33% for *F. thapsinum*, 9% for *F. verticillioides*, 5% for *F. andiyazi*, 2% for *F. sacchari* and 1% for *F. nygamai*. Both *F. sacchari* and *F. nygamai* were not detected in Parbhani and Patancheru isolates. Selected isolates from the above-mentioned 5 locations will be further analyzed through AFLP to identify toxigenic *Fusarium* spp. associated with grain mold in India.

RP Thakur and Rajan Sharma

**Contribution of host factors in mold resistance.** Several host morphological traits, such as panicle type, glume coverage, glume color, grain color and grain hardness are known to contribute to grain mold resistance in sorghum. We conducted a field trial consisting of 50 diverse sorghum lines including grain mold susceptible (SPV 104) and resistant (IS 8545) checks. The experiment was conducted. The sprinkler irrigation was provided twice a day for 30 min each on rain-free days from flowering to physiological maturity to provide high humidity

(>90% RH) essential for mold development. The grain mold scores were recorded at physiological maturity using a 1 to 9 scale, where 1 = no mold infection (highly resistant) and 9 > 75% molded grains on a panicle (highly susceptible). Data on morphological traits were also recorded at physiological maturity. Five panicles from each test line were harvested to study the grain hardness. The mean grain mold scores ranged from 1.4 to 9.0 in the test lines. Data on morphological traits will be correlated with the average grain mold severity scores of 50 sorghum lines to determine the relative contribution of different morphological traits in grain mold resistance.

**Role of phenolics in grain mold resistance.** Resistance to grain mold is a complex trait and several biochemical traits have been shown to be associated with resistance. Phenolic compounds in sorghum caryopses are reported to improve resistance to insects, fungi and other pathogens and cultivars with high tannin content have been used as a source of mold resistance. We estimated Flavon-4-ols in seed samples of 6 susceptible (SGMR 3-3-5-6, PVK 801-4, IS 36469C 1187-1-2-9-8-2, SP 72521-2-6-6-6, SPV 104, Bulk Y) and 11 resistant (IS 12932-2, IS 13969-1, SGMR 24-5-1-2, SGMR 11-3-5-1, ICSB 377, IS 8219-1, SGMR 40-1-2-3, IS 41397-3, ICSB 402-3, ICSB 402-1-2, SPV 462-3) lines of sorghum to find out the likely association with mold resistance. Mean Flavon-4-ols values of grain mold resistant and susceptible sorghum lines were distinctly different from each other. More Flavon-4-ols got accumulated in the methanol and acidified methanol extracts of both molded as well as non-molded grains of resistant lines than in susceptible lines. Similarly, range of Flavon-4-ols extracted both in methanol as well as acidified methanol was very large in the resistant lines, whereas it was very narrow for the susceptible lines. More Flavon-4-ols were detected in the colored grains than in the white grains. In most of the lines, molded grains recorded more Flavon-4-ols than non-molded grains. Considerable increase in the Flavon-4-ols content in the methanol extract was also observed in the molded grains of a white-grain resistant line SPV 462-3. This indicates that expression levels of Flavon-4-ols in the biosynthetic pathway are enhanced in response to the pathogen attack. Therefore, concentration of Flavon-4-ols in the mature sorghum seed can give an indication about the expected reaction of the sorghum cultivars to grain mold and differential levels of Flavon-4-ols can be used as a biochemical marker for grain mold resistance. However, the results need further confirmation using susceptible and resistant lines following artificial inoculations under greenhouse conditions.

**Influence of weather variables on grain mold development.** We studied the influence of weather variables, temperature (T) and relative humidity (RH) on sorghum grain mold development. The T and RH data, and grain mold severity scores collected from an ICAR-ICRISAT collaborative Sorghum Grain Mold Resistance Stability Nursery (SGMRSN) conducted at four locations (Coimbatore, Dharwad, Parbhani and Patancheru) for two rainy seasons 2005 and 2006 were used for this study. The weekly averages (across locations and seasons) of T (Tmax and Tmin) and RH (RHmax and RHmin) for a 2-month post-flowering period (grain-filling to physiological maturity period) were correlated with the average grain mold severity scores of 32 sorghum lines of the SGMRSN. Positive and significant correlations ( $r = 0.96$ ,  $P < 0.05$ ) were found between average weekly Tmin (18.5 to 22.5°C) during the standard 37<sup>th</sup> and 38<sup>th</sup> week (the 1<sup>st</sup> and 2<sup>nd</sup> weeks after panicle emergence) and the average grain mold severity of sorghum lines. This two-week period coincided with the anthesis and ovary fertilization stages of most sorghum lines during which time infection by mold pathogens took place. Similarly, significant positive correlation was found between the average RHmax (76 to 96%) during the standard 41<sup>st</sup> and 42<sup>nd</sup> week (the 5<sup>th</sup> and 6<sup>th</sup> week after panicle emergence) and the average grain mold severity ( $r = 0.87$ ,  $P < 0.05$ ). This period, for most sorghum lines, coincided with hard-dough to physiological maturity stages, and during this period infected grains, under high humidity conditions, showed rapid colonization by various mold fungi. Such infected grains developed growth of other saprophytic fungi as well when left in the field beyond physiological maturity. The regression analyses showed a near-linear relationship between Tmin and grain mold severity scores ( $R^2 = 0.96-0.99$ ), and between RHmax and grain mold severity scores ( $R^2 = 0.98-0.99$ ). Thus, the two most important weather variables, Tmin during anthesis to fertilization stage and RHmax during hard-dough to grain maturity stage appeared critical for infection and grain colonization by major mold pathogens (species of *Fusarium*, *Curvularia* and *Alternaria*) in the sorghum grain mold complex.

RP Thakur and Rajan Sharma

*MTP output Target 2007 6.1.1 SO: Ten sweet sorghum lines with high biomass and tolerance to stem borer and foliar diseases developed (BVS/R/HCS/RPT/RS)*

*Internal output target S 6A.1: High biomass forage/sweet sorghum lines with tolerance to shoot pests/foliar diseases, bold grain lines with resistance to shoot fly for post-rainy season, and high-yielding sorghum lines with resistance to grain mold for rainy season developed*

### **Activity S 6A.1.1: Selecting high biomass forage and sweet sorghum lines with tolerance to insect and foliar diseases, and grain sorghum with tolerance to grain mold**

**Downy mildew resistance in sweet sorghum hybrid parent lines:** Twenty B-lines and 16 R-lines along with one variety (SSV 84) and one hybrid (NSSH 104) were evaluated for resistance to sorghum downy mildew using the sandwich technique under greenhouse conditions during August 2007. A known DM resistant line, QL 3 and 3 susceptible lines (IS 3089, H 112 and 296B) were included as checks. The lines were evaluated in 3 replications, one pot (15 cm dia) per replication, with 30 - 35 seedlings per pot. Downy mildew incidence was recorded 14 days after inoculation. Of the 20 B-lines tested, one B-line (ICSB 690) was disease free, whereas, ICSB 565 and ICSB 545 showed 7 and 28% incidence, respectively, compared to 100% incidence in the susceptible checks (H 112 and 296B), and 11% in the resistant check, QL 3. All the 16 R-lines were highly susceptible (93-100% incidence).

**Anthraxnose resistance in sweet sorghum hybrid parent lines:** Twenty B-lines and 16 R-lines were evaluated for resistance to leaf anthracnose along with one variety (SSV 84) and a hybrid (NSSH 104), and resistant (A 2267-2) and susceptible (H 112) checks. The experiment was conducted in a completely randomized block design with 2 replications, 2 rows of 4 m length. The plants were whorl-inoculated with pathogen-infested sorghum grain 30 days after seedling emergence, and over-head sprinkler irrigation was provided for maintaining high humidity (>90%RH) required for disease development. Data on latent period (days from inoculation to symptom appearance on leaf lamina), and disease reaction (R = resistant- no infection or chlorotic flecks; MR = moderately resistant- brown spots without sporulation; and S = susceptible-lesions with sporulation), and disease severity (on 1-9 scale) were recorded on whole plant basis at soft dough stage. Of the 20 test B-lines, 11 lines (ICSB 279, ICSB 311, ICSB 453, ICSB 468, ICSB 479, ICSB 480, ICSB 487, ICSB 514, ICSB 545, ICSB 565 and ICSB 722) were resistant ( $\leq 3.0$  score) compared to 9.0 score on H 112. The latent period in the B-lines varied from 5.0 (ICSB 652) to 12.5 days (ICSB 453) compared to 5.0 days in H 112. Similarly, 5 R-lines (IS 23526, NSS 254, SSV 53, SPV 422 and ICSV 93046) were resistant ( $\leq 3.0$  score), and 7 lines (E 36-1, IS 21260, IS 2331, IS 23526, NSS 254, SP 4481-1 and SSV 53) exhibited MR disease reaction. The latent period among R-lines varied from 5.0 (SP 4511) to 8.5 days (SPV 422) compared to 5.0 days in a susceptible line, H 112 and 8.0 days in a resistant line, A 2267-2. Parent lines having resistance to downy mildew and anthracnose can be used to develop sweet sorghum hybrids having resistance to foliar diseases.

RP Thakur, R Sharma and BVS Reddy

**Sweet sorghum population:** Sweet sorghum varieties and germplasm lines were planted along with SSV 74 F<sub>4</sub> and SSV 84 F<sub>4</sub> crosses bulks for introgression. However, due to earliness of F<sub>4</sub> bulk and late flowering of sweet sorghum varieties, introgression could not be carried out successfully. However, 57 steriles and 75 fertiles from SSV 74 F<sub>4</sub> bulk and 144 steriles and 137 fertiles from SSV 84 bulk were harvested. The introgression will be repeated for the development of sweet sorghum population.

**High tillering population:** Based on the tillerability and biomass, 18 steriles and 38 fertiles were harvested from the ICSB HT C<sub>11</sub> population bulk, 4 steriles and 15 fertiles with tillers were harvested from the SSV 74 F<sub>4</sub> bulk and 4 steriles and fertiles with tillers were harvested from the SSV 84 F<sub>4</sub> bulk. Steriles and fertiles will be mixed in a 3 : 1 ratio to constitute the C<sub>12</sub> population bulk, SSV 74 F<sub>5s</sub> bulk and SSV 84 F<sub>5s</sub> bulk. These will be advanced during 2007 post-rainy season.

We also evaluated 20 sweet stalk B-lines and 16 sweet stalk R-lines for downy mildew reaction in glasshouse using sandwich technique for anthracnose (artificial inoculation) and grain mold reactions during 2007 rainy season. Among the B-lines, ICSB 690, and ICSB 565 were resistant, and ICSB 545 moderately resistant to downy mildew; eight B-lines (ICSB 271, 453, 479, 480, 545, 690, 722 and ICSB 729) were resistant to grain mold, and 17 B-lines were moderately-resistant to anthracnose. Among the R-lines; three R-lines (NSS 254, SP 4482-1 and SP 4511-2) were resistant to grain mold; and seven R-lines (E 36-1, IS 21260, IS 2331, IS 23526, NSS 254, SP 4481-1 and SSV 53) were moderately resistant to anthracnose. No resistance was observed in R-lines for downy mildew.

BVS Reddy and A Ashok Kumar

*Milestone: At least 5 sorghum lines with large grain, high grain yield and tolerance to shoot fly for post-rainy season adaptation developed (BVS/R/HCS) 2008*

**Evaluation of segregating material for resistance to shoot fly, *Atherigona soccata* during the post-rainy season:** During the post rainy season 2006/07, 205 F<sub>5</sub> lines along with the resistant, IS 18551 and susceptible,

Swarna checks, were evaluated for shoot fly resistance in a randomized complete block design with three replications. Deadheart incidence ranged from 5.7 to 83.6%, and 76 lines suffered <30% deadheart incidence compared to 19.7% in the resistant check, IS 18551, and 83.6% in Swarna. In another trial, 166 F<sub>6</sub> lines were evaluated for shoot fly resistance along with IS 18551 and Swarna. Deadheart incidence varied from 17.9 to 91.6% in the test material. Nine lines suffered <25% deadhearts compared to 28.3% in the resistant check, IS 18551, and 83.8% in Control Swarna.

In the F<sub>7</sub> trial, 19 lines were evaluated for shoot fly resistance along with resistant check IS 18551, and susceptible check Swarna. Deadheart incidence in the test material varied from 14.4 to 88.1%, and the lines 105-2, 104, 102, 107-3, 31`83-1, 114-1 and 103 suffered <40% deadhearts compared to 37.2% in the resistant check, IS 18551, and 86.0% in Swarna.

HC Sharma and BVS Reddy

*Milestone: Ten high yielding grain mold tolerant sorghum lines developed for rainy season adaptation (BVSR/RS) 2010*

**Grain mold resistance in R-lines:** Seventy-three R-lines along with 1 resistant and 2 susceptible checks were evaluated to confirm their resistance. The experiment was conducted in a RBD with 2 replications. Sprinkler irrigation was provided twice a day for 30 min each on rain-free days from flowering to physiological maturity to provide high humidity (>90%) essential for mold development. The grain mold scores were recorded at physiological maturity using a 1 to 9 scale, (1 = no mold infection, and 9 = >75% molded grains). The mean grain mold scores on test genotypes ranged from 4.8 to 9.0 compared to 2.0 on resistant check (IS 8545) and 8.6 to 9.0 on the susceptible checks (296 B and Bulk Y). Only one line with moderate level of resistance was identified, while the remaining lines were susceptible to grain molds.

RP Thakur, R Sharma and BVS Reddy

#### **Activity S 6A.1.2: Developing QTL mapping populations for economic yield components of sweet sorghum**

*Milestone: Two F<sub>5</sub> sorghum RIL mapping populations (300 lines each) available for genotyping and multilocational phenotyping for biomass yield, sugar content and sugar extraction characteristics (CTH/BVSR) 2010*

During 2007 rainy season, 5 F<sub>1</sub>s derived from the parents contrasting for stalk sugar content were advanced to F<sub>2</sub> generation. The parents are being genotyped for estimating parental diversity. Based on the genotyping results, crosses with more diverse parents will be made to derive the mapping populations (RILs).

BVS Reddy

*Milestone: SSR-anchored DArT marker linkage maps (>250 marker data points per RIL) available for the two sorghum RIL populations (CTH/SPD) 2010*

**SSR-anchored DArT marker linkage maps:** Working toward this milestone in 2007, we advanced several plant-by-plant crosses of elite sorghum genotypes showing substantial diversity based on SSR marker fingerprinting (diversity >0.70 based on allelic variation across 75 well-distributed SSR loci) and differences in sweet sorghum productivity traits including biomass yield and sugar content. After polyhouse advancement to produce F<sub>2</sub> seed from true-to-type F<sub>1</sub> plants of 13 plant-by-plant crosses, eight F<sub>2</sub> populations (based on four parental line pairs) of >400 individuals were advanced to F<sub>3</sub>. These F<sub>3</sub> families will be advanced two generations, to F<sub>5</sub>, during the coming year. Parentage of the RIL populations currently under development for this set of traits include:

#### **Pedigree**

(BTx623-P16 × ICSR 93024-1-P03)-P22  
 (BTx623-P24 × ICSR 93024-1-P05)-P02  
 (BTx623-P02 × S35-P08)-P16  
 (BTx623-P07 × S35-P03)-P17  
 (ICSV 93046-P01 × S35-P04)-P15  
 (ICSV 93046-P08 × S35-P01)-P04  
 (SP 39105-P07 × ICSR 93024-1-P08)-P16

#### **Trait combination**

Low biomass, not sweet × High biomass, sweet  
 Low biomass, not sweet × High biomass, sweet  
 Low biomass, not sweet × Low biomass, sweet  
 Low biomass, not sweet × Low biomass, sweet  
 High biomass, sweet × Low biomass, sweet  
 High biomass, sweet × Low biomass, sweet  
 High biomass, sweet × High biomass, sweet

(SP 39105-P01 x ICSR 93024-1-P05)-P13 High biomass, sweet × High biomass, sweet

In addition, a diallel cross was generated between available sources of the brown midrib trait in order to determine which of these sources carry allelic brown midrib mutations. The brown midrib trait is conferred by mutations in genes controlling enzymes in the lignin biosynthesis pathway, and these genes are expected to have major role in sweet sorghum juice extraction characteristics.

CT Hash, SP Deshpande and BVS Reddy

### **Activity S 6A.1.3: Selecting for high grain yield and large grain sorghum lines with resistance to shoot fly and adaptation to post-rainy season**

*Milestone: Sorghum lines (5) with large grain and high grain yield and less susceptible to shoot fly with postrainy season adaptation developed (BVSR/HCS) 2008*

Crosses will be made in 2007 postrainy season, involving grain mold resistance sources and high yielding B-lines.

BVS Reddy, A Ashok Kumar and R Sharma

Under this activity area in 2007 we conducted multi-locational screening during the rainy season and postrainy season of the shoot fly response of shoot fly resistance QTL introgressions from donor parent IS 18551 in the genetic backgrounds of agronomically elite shoot fly-sensitive seed parent maintainer lines BTx 623 and 296B. A total of 104 QTL introgression lines were screened at two locations (Patancheru and Rajendranagar) in replicated late-rainy season and early postrainy season trials and nurseries. We are awaiting compilation of the postrainy season screening data sets before compiling results; however, the following brief summary of Patancheru rainy season results is possible.

64-entry trial (32 test entries in BTx 623 background and 32 controls) evaluated as 2-row plots of 4-m length in 4 replications:

Four single-plant BC3-derived selections homozygous for the SBI-10 QTL introgression (increasing both seedling glossiness and trichome density) averaged 82% deadhearts incidence 14 days after emergence (DAE), 96% plants with eggs 14 DAE, and a seedling glossiness score of 3.6 at 9 DAE, compared to values of 93% deadhearts, 98% plants with eggs, and a seedling glossiness score of 5.0 for shoot fly susceptible recurrent parent BTx623, and 68% deadhearts, 94% plants with eggs, and a seedling glossiness score of 1.1 for shoot fly resistance donor parent IS 18551. Thus this single shoot fly resistance QTL region on SBI-10 appears to control a substantial portion of the resistance available from donor parent IS 18551, and this portion of the shoot fly resistance from this donor parent should be relatively easy to manipulate in a marker-assisted breeding program.

20-entry trial (14 test entries in 296B background and 6 controls) evaluated as 2-row plots of 2-m length in 3 replications:

Four single-plant BC3-derived selections homozygous for the SBI-05 glossiness QTL introgression averaged had seedling glossiness scores 9 DAE of 1.4 to 2.1, compared with scores of 0.3 to 0.7 for donor parent IS 18551 and 4.0 to 4.1 for recurrent parent 296B, but at least three of the four lines showed no improvement in shoot fly deadhearts incidence compared to their moderately shoot fly susceptible recurrent parent 296B. This suggests that the SBI-05 glossiness QTL from donor parent IS 18551 may not be substantially involved in host plant resistance to sorghum shoot fly, and thus need not be a target for marker-assisted selection.

84-entry trial (72 test entries in 296B background and 3 controls repeated 4 times each) evaluated as 1-row plots of 2-m length in 2 replications:

No significant improvements in shoot fly resistance could be detected in this low-replication small-plot trial. Further seed multiplication of these entries is needed to permit testing in sufficiently large numbers of replications of larger plot trials before the quantitative differences between entries can be accurately estimated.

In addition, we made the first crosses (to cytoplasmic male-sterile lines ATx623 and 296A) to initiate male-sterility conversion of the best available shoot fly resistance QTL introgression lines, producing the F1 seed during the rainy season sowing. Two additional generations of backcrossing, accompanied by marker-assisted selection in the A1-cytoplasm BC1F1 progenies, will be required to produce true-breeding A/B-pairs for each of

the target shoot fly resistance QTLs in these two important seed parent maintainer genetic backgrounds. This conversion process should be completed during 2008.

CT Hash, SP Deshpande, S Senthilvel and HC Sharma

#### **Activity S 6A.1.4: Selecting for high grain yield and grain mold tolerant sorghum lines**

*Milestone: Sorghum lines (5) with high grain yield and less susceptibility to grain mold developed for rainy season adaptation (BVS/RPT) 2009*

**The R-reaction progenies (73) derived from crosses of grain mold resistant lines, high yielding B-lines, and varieties were screened for grain mold tolerance in 2007 rainy season. Forty-one progenies with resistance to grain molds were selected and planted in 2007 postrainy season for grain yield evaluation.**

BVS Reddy/A Ashok Kumar/RP Thakur

#### **Activity S 6A.1.5: Identification of QTL linked to stem borer resistance in sorghum**

*Milestones: QTLs linked to stem borer resistance for use in sorghum improvement identified (CTH/HCS/BVSR) 2012*

In 2007, we made 61 plant-by-plant crosses between nine pairs of sorghum inbred lines previously demonstrated to differ in their stem borer resistance, and advanced several of these crosses to F2 seed. First, during the 2006/07 postrainy season, we made line × line crosses (including reciprocals) of the following pairs in which the first-listed parent is stem borer resistant and the second is stem borer susceptible: ICSV 700 and ICSV 1, and IS 2205 and ICSV 1. During the 2007 rainy season, one plant-by-plant cross of each of four of the possible combinations (including reciprocals) between these two pairs of parental lines was advanced by selfing to produce single-plant-derived F2 populations. These four F2 populations will be advanced by two selfing generations during 2008.

In addition to the above crosses, we also produced plant-by-plant crosses between pairs of lines differing in their resistance to sorghum midge, including ICSV 700 and ICSV 745, IS 2205 and ICSV 745, ICSV 700 and AF 28, and IS 2205 and AF 28, in which the first-listed parent is stem borer resistant but midge susceptible, and the second parent is stem borer susceptible but midge resistant. Seed of 47 plant-by-plant crosses (including F1 seed as well as selfed seed of both parental plants) was harvested for future use in developing new sorghum mapping populations segregating for stem borer resistance and/or midge resistance.

CT Hash, SP Deshpande and HC Sharma

**Evaluation of mapping population for resistance to spotted stem borer, *Chilo partellus*:** To identify molecular markers associated with resistance to spotted stem borer, *Chilo partellus*, the mapping population based on ICSV 745 x PB 15220 was evaluated for stem borer resistance under artificial infestation in the field as a part of the thesis research. The mapping population (270 lines), along with the resistant (IS 2205) and susceptible checks (ICSV 1), and the parents (PB 15220 and ICSV 745) were planted in a balanced alpha design, and there were three replications. Data were recorded on leaf feeding (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), deadheart formation (%), leaf glossiness (1= highly glossy and 5 = non-glossy), leaf sheath and plumule pigmentation (1 = highly pigmented and 5 = Non-pigmented–green colored), stem tunneling (%), days to panicle initiation, recovery resistance (1= good recovery and 5 = poor), and agronomic score (1 = good and 5 = poor). There was a significant variation in the traits studied in the mapping population. Leaf damage rating (DR) was 5.52 in PB 15220 and 7.84 in ICSV 745 compared to 4.47 in the resistant check, IS 2205, and 7.97 in the susceptible check, ICSV 1. The RIL population mean was 6.5. Deadheart formation was 71.6% in PB 15220 and 80.7% in ICSV 745 compared to 46.2% in the resistant check - IS 2205, and 66.3% in the susceptible check ICSV 1. Leaf glossiness score was 4.61 in PB 15220 and 4.37 in ICSV 745 compared to 2.1 of the resistant check - IS 2205 and 3.7 of the susceptible check ICSV 1. Overall resistance score was 5.7 in PB 15220 and 7.7 in ICSV 745 compared to 4.2 in the resistant check, IS 2205, and 5.5 in the susceptible check, ICSV 1. Deadheart formation was significantly and negatively associated with agronomic score, leaf glossiness, overall resistance score, and recovery resistance. Leaf feeding was positively associated with overall resistance and recovery scores, but negatively associated with leaf angle, seedling pigmentation and agronomic scores.

HC Sharma, CT Hash, B VS Reddy and SP Deshpande

### **Activity S 6A.1.6: Developing sorghum QTL mapping populations for biological nitrification inhibition (BNI)**

*Milestone: QTLs linked to biological nitrification inhibition identified (CTH/SPD/VV) 2012*

In 2007, we made 47 plant-by-plant crosses between nine pairs of sorghum inbred lines previously demonstrated to differ in their BNI activity, and advanced these to F<sub>2</sub> seed. First, during the 2006/07 postrainy season, we made line × line crosses (including reciprocals) of the following pairs in which the first-listed parent has low BNI activity and the second has high BNI activity: BTx 623 and IS 9830, BTx 623 and SPV 422, BTx 623 and PKV 801, IS 720 and IS 9830, IS 720 and SPV 422, IS 720 and PKV 801, 296B and IS 9830, 296B and SPV 422, and 296B and PKV 801. During the 2007 rainy season, one plant-by-plant cross of each of these 18 combinations (including reciprocals) was advanced by selfing to produce single-plant-derived F<sub>2</sub> populations. A subset of these 18 F<sub>2</sub> populations will be advanced two selfing generations during 2008.

In addition, seed of four existing ICRISAT sorghum RIL populations [ICSP 71000, comprising of 268 F<sub>10</sub> random inbred lines derived from (ICSV 745 × PB 15520)-1; ICSP 72000, comprising of 361 F<sub>10</sub> random inbred lines derived from (ICSV 745 × PB 15881-3)-1; ICSP 73001, comprising of 221 F<sub>7</sub> random inbred lines derived from (N13 × E 36-1); and ICSP 74000, comprising of 223 F<sub>7</sub> random inbred lines derived from (IS 9830 × E 36-1)] was multiplied and seed samples conserved in the ICRISAT Genebank for long term conservation. Seed samples from two of these ICRISAT sorghum RIL populations (ICSP 7200 and ICSP 7400), based on parental line pairs previously demonstrated to differ significantly in BNI activity, were sent to collaborators at the Japan International Research Center for Agricultural Sciences (JIRCAS) to be phenotyped for BNI activity and root exudation of sorgoleone (a compound released from sorghum roots that shows very high levels of BNI activity and is hypothesized to be the main component of sorghum root exudates responsible for BNI function).

Finally, in the late rainy season we sowed nine sorghum entries in two replications of 4-row plots of 4-m length, providing nitrogen in the form of ammonium sulfate. During the mid-flowering stage of crop growth, soil samples were collected from the rhizospheres of sorghum plants in each of these plots. These soil samples are to be assessed for their BNI activity at JIRCAS. The entries included sorghum genotypes previously characterized as having high (IS 9830, PKV 801 and SPV 422), intermediate (ICSV 745 and E 36-1), or low (PB 15881-3, IS 720, BTx623 and 296B) BNI activity.

CT Hash, SP Deshpande and V Vadez

### **Output B. Knowledge of the improvements of the biotechnological and conventional tools designed to facilitate drought and salinity tolerance breeding and germplasm of mandate crops and associated capacity building made available to partners internationally**

*Internal output target GN 6B.1: Develop groundnut varieties with tolerance to drought using conventional and biotechnological approaches*

#### **Groundnut**

##### **Activity GN 6B.1.1: Develop high yielding groundnut varieties tolerant to drought**

*Milestone: 15-20 new high yielding drought tolerant breeding lines made available to NARS annually (SNN/RA/VV) Annual*

In the postrainy season, early generation breeding materials and advanced breeding lines were evaluated by subjecting them to moisture stress by withholding alternate irrigation in the normal irrigation schedule (12 days interval), starting from 65 DAS until harvest. The elite and advanced trials were also grown under full irrigation in the same field to assess the full yield potential of the breeding lines. We evaluated 409 F<sub>2</sub>-F<sub>7</sub> bulks and 117 single plants during the 2006/07 postrainy season, and 390 single plant selections were made. Of these, 79 selections were included in replicated yield trials. The most promising (5) high yielding selections came from crosses (ICR 48 x ICGX 000052) and (ICR 24 x ICGX 02267). During the rainy season, 633 F<sub>2</sub>-F<sub>8</sub> bulks were sown for further evaluation. From these, 321 F<sub>2</sub>-F<sub>8</sub> bulks and 128 single plants were sown for evaluation. The most promising selections came from (ICGX 000047 x ICGX 970201).



We also evaluated 112 advanced breeding lines (including controls) in six replicated trials and 18 advanced breeding lines in an augmented trial in the 2006/07 post-rainy season. In 2007 rainy season, 217 advanced breeding lines (including controls) in 10 replicated trials were evaluated. Analysis of data is in progress. During the 2006/07 post-rainy season, in an Advanced Trial-1 (irrigated), 3 lines ( $5.9 - 5.7 \pm 0.24 \text{ t ha}^{-1}$ ) significantly out-yielded the best control ICGV 00350 ( $5.0 \text{ t ha}^{-1}$  pod yield; 66% shelling outturn; 44.0 g 100-seed weight). The best entry in the trial was ICGV 05159 ( $5.9 \text{ t ha}^{-1}$ , 60%, 38.0 g). In ICRISAT – ARS ATP Trial-1, 5 lines ( $5.8 - 5.27 \pm 0.41 \text{ t ha}^{-1}$ ) significantly out-yielded the best control ICGV 91114 ( $4.2 \text{ t ha}^{-1}$  pod yield; 75% shelling outturn; 53.0 g 100-seed weight). The best entry in the trial was ICGV 06436 ( $5.8 \text{ t ha}^{-1}$ , 74%, 49.0 g). In Preliminary Trial-1, evaluated under stress, Entry no. 7 ( $2.7 \text{ t ha}^{-1}$  pod yield; 61% shelling outturn; 32.0 g 100-seed weight) significantly out-yielded the best control ICGV 02266 ( $1.5 \pm 0.40 \text{ t ha}^{-1}$ ; 50%; 30.0 g).

SN Nigam and R Aruna

*Milestones: 5-10 new sources of resistance to drought identified (SNN/RA/VV) 2009*

During the 2006/07 post-rainy and 2007 rainy season, 29 new crosses were made to generate populations for resistance to drought and high pod yield with desirable agronomic traits. ICGV nos. 05151, 06423, 06441, 06443, 91116, 04158, 04160, 05159, 86325 and 00308 (drought tolerant lines) and ICGX -030108-P2-B1 were used in the hybridization program.

SN Nigam and R Aruna

In 2006, 440 genotypes of groundnut were screened for transpiration efficiency (TE) at Patancheru during April. The genotypes included mini-core collection, breeding lines and a set of diverse germplasm proposed from groundnut breeding. A 4-fold variation for TE was found. In 2007, 10 contrasting genotypes were tested again for TE during March. Genotypes ICGV 86015 and ICGV 86105 had consistent high TE values across experiments. The entire set is being tested again in 2007. Contrasting genotypes will be used to develop new mapping populations for TE. Mapping population will also be used to understand genotype-by-environment variation for TE across a range of vapor pressure deficit (VPD) conditions.

V Vadez and L Krishnamurthy

*Milestone: 15-20 advanced lines tested in Anantapur in India and other drought prone areas (SNN/RA/VV) 2009*

A trial was formulated to select varieties specially suited for drought prone Anantapur district in Andhra Pradesh. Based on the results obtained from both Anantapur and ICRISAT during the last two years (details given in Archival reports 2005 and 2006), we selected 16 lines for further evaluation at ICRISAT and ARS, Anantapur. These lines were further evaluated in 2006 rainy season, and eight lines were selected. This trial could not be conducted at Anantapur during the post-rainy season as the district received very less rainfall during the 2006 rainy season. All the 16 lines were sown at Anantapur, for evaluation during the 2007 rainy season.

The Sixth IDRGVT was evaluated at ARS, Anantapur, for two consecutive years, rainy seasons 2005 and 2006. Due to the difference in rainfall pattern in both the seasons, yields in 2005 rainy season (mean pod yield  $1236 \text{ kg ha}^{-1}$ ) were higher than in 2006 rainy season (mean pod yield  $614 \text{ kg ha}^{-1}$ ). ICGV 01263 (pod yield  $1464 \text{ kg ha}^{-1}$ ; haulm yield  $1514 \text{ kg ha}^{-1}$  in the 2005 rainy season; pod yield of  $772.7 \text{ kg ha}^{-1}$  during the 2006 rainy season) outperformed the controls in both the seasons. ICGV 00350, in addition to good pod yield ( $1234 \text{ kg ha}^{-1}$  in 2005 rainy season and  $757.6 \text{ kg ha}^{-1}$  in the 2006 rainy season), also gave good haulm yield ( $2073 \text{ kg ha}^{-1}$  in 2005 rainy season and  $1436 \text{ kg ha}^{-1}$  in 2006 rainy season). In a drought prone location like Anantapur, in addition to pod yield, haulm yield also is of significance, as groundnut haulm is an important source of fodder for the cattle. Another genotype, ICGV 00340 (pod yield  $1330 \text{ kg ha}^{-1}$  and haulm yield  $1744 \text{ kg ha}^{-1}$  in 2005 rainy season and  $831.5 \text{ kg ha}^{-1}$  and  $1566 \text{ kg ha}^{-1}$  in 2006 rainy season) also had high shelling percentage (67% in 2005 rainy season and 70% in the 2006 rainy season). This genotype ranked first during the 2006 rainy season, when rainfall was very low and also had similar 100-seed weight (44 g in 2005 rainy season and 45 g in 2006 rainy season). ICGV 00350 has been proposed for evaluation in multi-location trials in the district. Results would be available after evaluating this genotype for at least two years.

SN Nigam, R Aruna and V Vadez

*Milestone: Physiological traits in 3 - 4 superior sources for drought tolerance dissected (VV/SNN/RA) 2010*

We have designed and tested a lysimetric system in which groundnut genotypes are grown in long and large PVC cylinders (20 cm in diameter and 1.2 m long) (Fig. 5).

The soil volume available to each individual plant is equivalent to the soil volume available in the field at usual planting densities (25 - 30 plant m<sup>-2</sup>). This system will allow us to measure water uptake by plants grown in a real soil profile under conditions of water deficit and to understand how roots contribute to drought tolerance, and stress conditions. We have also identified a set of breeding lines or pre-released varieties that have shown consistently good performance under drought conditions, and these will be assessed in this system, along with known drought sensitive checks. Preliminary experiments indicated that the kinetics of water uptake varies across genotypes, with some genotypes having a “conservative” use of water, being able to take up water for long after being exposed to stress, whereas other genotypes have a more “opportunistic” behavior, tapping lot of water soon after stress, but running short of water later on.



**Figure 5. Use of PVC cylinders for root studies.**

V Vadez

#### **Activity GN 6B.1.2: Mapping and marker-assisted breeding for drought tolerance in groundnut**

*Milestone: QTL mapping of component traits of drought tolerance (TE) using available and suitable populations (VV/RA/SNN) 2008*

The phenotyping of one population developed to map QTLs for transpiration efficiency (TE) has been performed [ICGV 86031 (high TE) x TAG 24 (low TE)] in 2004 and 2005, and showed a good segregation pattern, with some transgressive segregation of a number of RILs reaching higher TE levels than the high TE parent, ICGV86031. Surrogate traits of TE such as SLA, SCMR and <sup>13</sup>C discrimination had a poor relationship with TE measured gravimetrically. These results are very important because these surrogates have often been recommended and used for their convenience in assessing TE, with the assumption that they bear a good relationship with TE. Our results indicate that care should be taken in using these surrogates as proxies for TE. The reason for the lack of relationship is unclear, and it seems that the phenotypic contrast between the 2 parents for SLA and SCMR was limited. It is likely that other mechanisms are involved in the TE differences.

The lack of polymorphic markers for the parents of this population has hampered the progress towards the identification of markers for TE. Efforts have been made, and 140 markers, polymorphic between these two parents, have been identified. This population will also be phenotyped in the field in 2007-08. Screening of parental genotypes with more than 900 SSR markers provided more than 120 polymorphic markers. Genotyping of the mapping population with all the polymorphic markers is in progress.

V Vadez, L Krishnamurthy, R Aruna and R Varshney

*Milestone: Range of variations for root traits assessed in groundnut germplasm (VV/SNN/RA/HDU) 2008*

Following the successful preliminary trials to assess water uptake by plants in a real soil profile mimicked by a long PVC tube, reported in the previous archival report, the rain-out-shelter (ROS) of ICRISAT has been modified into a root study facility in 2007 (see Fig.5). Four large trenches have been dug up and cemented. Each trench accommodates about 700 cylinders (1.2 m long and 20 cm diameter), each collared in a way that they can be lifted up and weighed using a hanging scale. This system will be used to assess the range of variation for water uptake upon exposure to water deficit, and also the kinetics of water uptake under water deficit. These traits will be compared to those under well-watered conditions.

V Vadez and L Krishnamurthy

*MTP output target 2007 6.2.1 GN: 3 mapping populations between contrasting parents to identify QTLs for salinity tolerance and component traits of drought tolerance developed*

The phenotyping of one population developed to map QTLs for transpiration efficiency (TE) has been performed (ICGV86031 (high TE) x TAG24 (low TE)) in 2004 and 2005, and showed in both cases a good segregation pattern, with some transgressive segregation of a number of RILs reaching higher TE levels than the high TE parent ICGV86031. In this work now published (Krishnamurthy et al. 2007), we found that the surrogate traits of TE such as SLA, SCMR and <sup>13</sup>C discrimination had poor relationship with TE measured gravimetrically. These results are very important because these surrogates have often been recommended and used for their convenience in assessing TE, with the assumption that they bear a good relationship with TE. Our results indicate therefore that care should be taken about using these surrogates as proxies for TE. The reason for the lack of relation is unclear, and it seems that the phenotypic contrast between the 2 parents for SLA and SCMR was limited. It may also be that other mechanisms are involved in the TE differences.

The lack of polymorphic markers for the parents of that population has hampered the progress towards the identification of markers for TE. Efforts have been made and about 140 markers, polymorphic between these two parents have been identified. This population will also be phenotyped in the field in 2007-08. Screening of parental genotypes with more than 900 SSR markers provided more than 120 polymorphic markers. Genotyping of the mapping population with all the polymorphic markers is in progress.

Vincent Vadez, L Krishnamurthy and Rajeev Varshney

Crosses between three salinity sensitive advance breeding lines (ICGV 00309, ICG 2777 and ICG 4343) and three salinity tolerant parents (ICGV 86155, ICGV 87921 and ICG 6892) were made during the 2007 rainy season. F1 seed has been harvested. Fresh crosses also will be made during the 2007/08 postrainy season to get more number of F1s. Initially, studies would be conducted to identify the best parental combination, and the combination identified would be advanced to make RIL population.

R Aruna and Vincent Vadez

From the repeat screening of salinity tolerant groundnut genotypes, we selected five tolerant genotypes and five susceptible genotypes. With these genotypes, we tested the effect of salt treatment applied either at sowing, or at flowering time in a number of biochemical indicators (ABA, proline, protein profiling, etc.), on leaf gas exchange measurement (transpiration and leaf conductance), and on transpiration efficiency. To do this, plants were grown up until flowering under control conditions (a genotype was considered flowered when over 50% of the plants had developed at least one flower). At flowering, the salt treatment was applied to the pots. A dose of 1.46 g NaCl kg<sup>-1</sup> soil was used. This was 25% higher than the dose used in the outdoors screening. We did that because this experiment was carried out under glasshouse conditions and we expected the VPD to be a lot lower under these conditions. Salt treatment was applied in three split doses in 3 consecutive days. Upon salt treatment, plants were weighed on alternate days. Samples for biochemical indicators were taken at 3 stages after treatment imposition, spread out during a 3-week period. Plants were harvested at 3 weeks for TE measurement. A separate set of plants with similar set of treatment were grown in larger pots, was treated in the same way and kept until maturity to measure salinity tolerance based on yield and relative yield reduction in these genotypes in those glasshouse conditions.

Vincent Vadez

*Milestone: QTLs for root traits identified (VV/SNN/RA) 2011*

As mentioned above, we are in the process of identifying several sets of parents with large contrast for TE, which could be used for development of mapping populations. Such work is under way and 14 genotypes (ICGV 86015, ICGV 86105, ICG 3933, ICG 4749, ICG 11515, ICG 3421 and ICG 1415 with high TE, and ICGV 99004, Chico, ICG 5016, ICG 5051, ICG 12370, ICG 4156 and ICG 11109 with low TE) have been identified. These genotypes have been crossed with one amphidiploid genotype received from EMBRAPA. Transpiration efficiency has also been assessed in this amphidiploid and the cultivated lines. Based on this repeat assessment, the number of crosses will be trimmed to a few in which the cultivated parent and the amphidiploid have large contrast for TE.

Based on repeat assessments of TE in contrasting lines from the 2006 screening, crosses between contrasting cultivated parents will be undertaken to develop mapping populations. New mapping populations between parents having high and low SPAD values [(ICGS 76 x ICGV 93291), (TMV 2 x CSMG 84-1) and (ICGV

99029 x ICGV 91284)] are being made. The population is in F<sub>3</sub> generation. Apart from advancing these lines to make recombinant inbred lines, these populations will also be studied for inheritance to SPAD and SLA.

V Vadez and R Aruna

*Milestone: Molecular markers ready for validation and use in introgression studies for abiotic and biotic stresses (VV/RA/SNN/RKV) 2009*

Identification of molecular markers for water use efficiency is in progress.

V Vadez and R Varshney

Internal output target GN 6B.2: High throughput molecular genetic and phenotyping platforms for drought and salinity stress and promising transgenic events of groundnut for tolerance to drought stress available for commercialization and introgression in locally adapted germplasm

#### **Activity GN 6B.2.1: Develop groundnut transgenic events for enhanced tolerance to drought**

*Milestones: 50 transgenic events of groundnut with DREB1A gene screened for drought tolerance in the contained greenhouse (KKS/VV/RA) 2007*

A transcription factor *DREB1A* from *Arabidopsis thaliana*, driven by the stress inducible promoter from the rd29A gene as earlier reported, was introduced in a drought-sensitive peanut cultivar JL 24 through *Agrobacterium tumefaciens*-mediated gene transfer. Over 50 transgenic events were produced and advanced to the T5 generation. As reported earlier, the transformants were screened by polymerase chain reaction (PCR), RT-PCR and Southern analysis for the presence and expression of *DREB1A*. Assessment of 20 transgenic events carried out by using the soil drying experiments showed differences in their transpiration responses to soil drying. There was a significant variation amongst the tested events under drought stress for transpiration efficiency (TE). Work on the selection of transgenic events with superior transpiration efficiency (TE) is ongoing to test whether the overexpression of *DREB1A* helps in successful reproduction of plants under water deficit by exposing them to a drought spell during the reproductive phase.

Assessment of *DREB1A* transgenics for water uptake and rooting pattern has been carried out under water deficit in a lysimetric system, ie, long PVC tubing mimicking a field-like soil profile. Motivated by the encouraging results of the first experiment, the *DREB1A* transgenic events of groundnut showing high TE were repeated. In this experiment, the better performing line RD 33 was also included along with the already tested lines RD 2, RD 11, RD 12, RD 19 and RD 20, and the non-transformed parent, JL 24. Where again *DREB1A* clearly enhances water uptake by 20 - 30% under water deficit compared to the control through an effect on root growth. Water uptake was related ( $r = 0.91$ ) with root dry weight below 40 cm depth. Results indicated that effect of *DREB1A* on root growth under drought stress was due to an effect on the root/shoot ratio, which dramatically increased under water stress.

In our ongoing efforts to improve the drought tolerance traits of agronomically elite genotypes of groundnut, we are also developing rd29A:*DREB1A* transgenic events of ICGV 86031, either by *Agrobacterium* mediated transformation or by introgression experiments. Introgression experiments were carried out using RD 2 with a consistent high TE, as male parent and ICGV 86031 as a female parent, to transfer the desired phenotypic trait for drought tolerance from the selected transgenic event to locally adapted groundnut germplasm by using conventional breeding. Four transgenic plants were crossed with ICGV 86031 in the controlled environment. Seed from two plants were harvested, 31 seeds were harvested from RD 2, 2-8-3-1-2 and 50 from RD 2, 2-8-3-1-5. Seeds from third plant are yet to be harvested. Detailed molecular analysis of the F<sub>1</sub> progenies thus produced is in progress. Further, the introgression studies would involve repetitive backcrossing of the positive F<sub>1</sub> hybrid plants with ICGV 86031.

KK Sharma, P Bhatnagar, V Vadez and R Aruna

*Milestone: At least 8 promising transgenic events of groundnut containing DREB1A gene identified and their drought tolerance characterized under contained field conditions (KKS/VV/RA) 2008*

Due to problems in getting permission from the Government of India to have transgenic groundnut evaluated in the field conditions, we have not been able to undertake field-testing. However, with the lysimetric system developed and described earlier, we were able to grow plants to maturity under water stress conditions and

compare events and wild type for their response to drought. This type of evaluation will be continued until a formal authorization for field testing is obtained.

*Milestone: Three promising transgenic events of groundnut identified for drought tolerance and characterized under contained field conditions (KKS/VV/RA) 2009*

This activity will be undertaken following the completion of proposed contained field testing in 2008.

*Milestone: One or two transgenic events of groundnut used for introgression into locally adapted genotypes with better adaptation and the progeny characterized and evaluated (KKS/VV/SNN/RA) 2010*

The activities have not yet been initiated.

*Milestone: 15-20 introgressed transgenic lines of groundnut with improved tolerance to water-limiting conditions evaluated and development of commercialization package initiated (KKS/VV/SNN/RA) 2011*

The related activities will be initiated after the best event has been identified followed by thorough characterization at the contained field level.

KK Sharma, P Bhatnagar, V Vadez and R Aruna

*MTP output target 2007 6.2.2 GN: At least 10 genotypes with superior salinity tolerance identified (VV/RA/SNN)*

#### **Activity GN 6B.2.2: Mapping and marker-assisted breeding for salinity tolerance in groundnut**

Screening of 288 genotypes of groundnut, including the mini-core collection, was performed in 2005 rainy season in outdoor conditions, in which the overall VPD conditions were relatively low (1.17 g salt kg<sup>-1</sup> Alfisol). The evaluation was based on yield under saline and controlled conditions, and related parameters (pod number, biomass, etc.). The screening was repeated in 2006-07 postrainy season (November 06-April 07), in which the VPD was relatively high to measure G x E interaction for salinity tolerance, and to identify a set of contrasting genotypes for yield under saline conditions.

We observed large G x E interaction for salinity tolerance among the genotypes tested. This was expected as the light, temperature and humidity conditions under which the accessions were tested varied a lot. Yet, we were able to identify a set of 31 genotypes (15 tolerant and 16 sensitive) that showed a consistent response across environments. These genotypes were screened with 21 markers to assess their diversity at DNA level, and then to choose the most suitable parents for crossing. Out of these, 18 showed polymorphisms between the lines. Interestingly, we found that genotypes JL 24 (sensitive) contrasted with ICG (FDRS) 10 (tolerant) across seasons. An RIL population from these 2 parents is being developed for leaf diseases, and is now at F<sub>5</sub> generation. Genotype CSMG 84-1 (sensitive) also contrasted with ICGS 44 and ICGS 76 (tolerant). RIL populations ICGS 44 x CSMG 84-1 and ICGS 76 x CSMG 84-1 have been developed for TE in the past years and are now at F<sub>8</sub> stage. These populations can be used to phenotype for salt tolerance and to identify QTLs for salinity tolerance. There is no relationship between yield potential under control conditions and yield performance under saline conditions. Therefore, absolute yield data under saline conditions were used to assess salinity tolerance. We also observed a weak relationship between biomass at maturity and the pod yield at maturity, which indicated that, though biomass is low under saline conditions, the genotypic differences in biomass under saline conditions do not explain differences in pod dry weight. We also measured stem and leaf Na accumulation in 2006. We found no relationship between stem Na, leaf Na, and pod yield. These results are contrary to most of the literature on salinity tolerance, where shoot Na accumulation contributes to salt tolerance. These results are similar finding to those in chickpea. The data indicated that salt accumulation in the shoot is not responsible for the differences in tolerance.

V Vadez, R Aruna and L Krishnamurthy

*Milestone: Mapping populations between contrasting parents for salinity tolerance developed to identify QTLs (VV/RA/SNN) 2008*

*Milestone: QTLs for salinity tolerance identified (VV/SNN/RA) 2011*

Crosses between three salinity sensitive advance breeding lines (ICGV 00309, ICG 2777 and ICG 4343) and three salinity tolerant parents (ICGV 86155, ICGV 87921 and ICG 6892) were made during the 2007 rainy season. Fresh crosses will also be made during the 2007/08 postrainy season to get more number of F<sub>1</sub>s. Initially, studies would be conducted to identify best parental combination, and advanced to make RILs.

R Aruna and V Vadez

## Chickpea

*Internal output target CP 6B.1: Identification of QTLs for drought avoidance root traits and salinity tolerance in chickpea*

### Activity CP 6B.1.1: Mapping and marker-assisted breeding for drought tolerance in chickpea

*Milestone: Molecular markers for additional QTLs for drought avoidance root traits identified (PMG/JK/LK/RKV) 2007*

**Agronomic evaluation of mapping population:** F<sub>9</sub> RILs of ICC 4958 x ICC 1882 (n = 264) and ICC 283 x ICC 8261 (n = 281) were evaluated for yield and various phenological and morphological traits during the postrainy season 2006-07. Both the populations showed large variability for all the traits. The yield in the RILs of ICC 4958 x ICC 1882 varied from 501 to 3045 kg ha<sup>-1</sup> and maturity ranged from 64 to 115 days. ICC 4958 (drought tolerant parent) yielded 2108 kg ha<sup>-1</sup>. The harvest index (HI) in the RILs ranged from 25 to 68.3 %. In the second RIL population, ICC 283 x ICC 8261, the yield varied from 73 to 2594 kg ha<sup>-1</sup> with the drought tolerant parent (ICC 8261) yielding 2004 kg ha<sup>-1</sup>. The maturity duration in the RILs was in the range of 98 to 124 days, while the HI varied 15.5 to 63.4 %.

PM Gaur, J Kashiwagi and R Varshney

**Phenotyping of mapping populations for root trait:** RIL mapping populations of ICC 4958 x ICC 1882 and ICC 283 x ICC 8261 have been phenotyped in tall PVC cylinder (120 cm height) culture systems with 3 replications. A large variability was obtained in root length density (RLD) and rooting depth (RDp) between the parental lines as well as RILs. The phenotyping of the root traits in RIL population of ICC 4958 x ICC 1882 will be repeated to confirm the results in 2007 postrainy season.

J Kashiwagi

**Genotyping of mapping population:** In order to genotype the RIL populations, the parental genotypes of the mapping populations (ICC 4958 x ICC 1882 and ICC 283 x ICC 8261) were screened with existing set of SSR markers (H series, NIPGR markers) together with the new set of markers (ICCM and CaM series), which have recently been developed at ICRISAT. So far, a total of 824 SSR markers have been screened (Table 4). As a result, 124 markers have been identified to be polymorphic in mapping population ICC 4958 x ICC 1882 and 150 markers in ICC 283 X ICC 8261. The genotyping of the ICC 4958 x ICC 1882 population with corresponding polymorphic markers is in progress.

**Table 4: Polymorphism in parental genotypes for root traits in chickpea.**

| Marker series | Total markers | Scorable markers | Polymorphic markers in ICC 4958XICC 1882 | Polymorphic markers in ICC 283 x ICC 8261 |
|---------------|---------------|------------------|------------------------------------------|-------------------------------------------|
| H series      | 233           | 153              | 36                                       | 42                                        |
| NIPGR         | 280           | 203              | 62                                       | 82                                        |
| ICCM          | 311           | 225              | 26                                       | 24                                        |
| Total         | 824           | 581              | 124                                      | 148                                       |

R Varshney, Nicy Varghese, J Kashiwagi and PM Gaur

*Milestone: QTLs for drought avoidance root traits validated (PMG/JK/LK/RKV) 2009*

One of the two populations developed above will be used for validation of QTLs for drought avoidance root traits.

*Milestone: MABC-derived drought tolerant lines available from 2-3 locally adapted cultivars (PMG/JK/LK/RKV) 2011*

**Drought avoidance root traits introgressed in farmer's preferred cultivars through MABC:** Three farmer-preferred cultivars, JG 11 (desi type) and Chefe and KAK 2 (kabuli type) were selected for introgression of drought avoidance root traits (high root length and high root depth) from the lines ICC 8261 (kabuli) and ICC 4958 (desi) through marker-assisted backcrossing (MABC). F<sub>1</sub>s of three crosses (Chefe x ICC 8261, KAK 2 x ICC 8261 and JG 11 x ICC 4958) made during 2006 were grown in the post-rainy season 2006-07 along with parents. Backcrosses were made between F<sub>1</sub>s and elite cultivars [Chefe x (Chefe x ICC 8261), KAK 2 x (KAK 2 x ICC 8261), and JG 11 x (JG 11 x ICC 4958)]. The BC<sub>1</sub>F<sub>1</sub> population of the 3 crosses will be subjected to foreground and background selection by SSR markers.

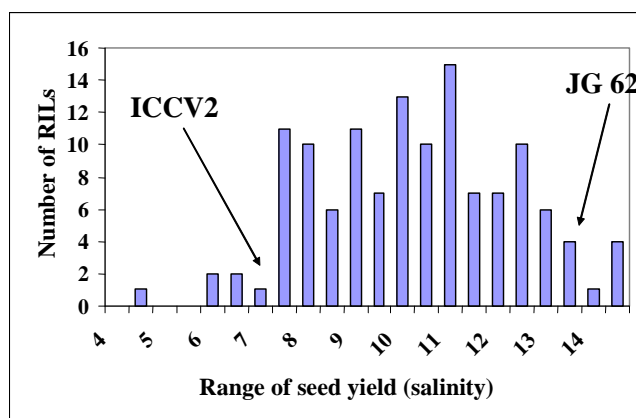
PM Gaur, J Kashiwagi and R Varshney

*MTP output target 2007 6.2.1 CP: Phenotyping of ICCV 2 x JG 62 mapping population for salinity tolerance completed and data analyzed with available markers data for QTL mapping (VV/LK/RKV/PMG)*

Data on root traits on two RIL populations (ICC 4958 x ICC 1882 and ICC 283 x ICC 8261) has been collected. A total of 124 markers polymorphic in mapping population ICC 4958 x ICC 1882 and 150 markers in ICC 283 x ICC 8261 have been found. The genotyping of the ICC 4958 x ICC 1882 population with corresponding polymorphic markers is still in progress. The genotyping is taking a longer time than initially anticipated as there are now a larger number of SSR markers available. Genotyping with the remaining markers and statistical analysis of the data for identification of additional markers for root QTLs would be completed in 2008.

#### Activity CP 6B.1.2: Mapping and marker-assisted breeding for salinity tolerance in chickpea

The population developed between JG 62 and ICCV 2, tolerant and sensitive to salinity stress, respectively, (over two years of screening) was phenotyped for two consecutive years (2005-06 and 2006-07). There was a good agreement between the seed yield data obtained across two years ( $r^2 = 0.47$ ). The segregation pattern was also good, with JG 62 and ICCV 2 being on the extreme of the ranking of genotypes (Fig. 6).



**Figure 6: Segregation for seed yield under salinity in chickpea cross ICCV 2 x JG 62.**

In previous screening for salinity tolerance, we had found evidence that the time to flowering is related to the level of salinity tolerance, under short growing season length that is prevalent at ICRISAT-Patancheru. Therefore, part of the differences in tolerance between ICCV 2 and JG 62 is explained by 17 days difference in their time to flowering under saline conditions. When the frequency distribution for seed yield under saline conditions was made, it was clearly evident that discrimination occurred for time to flowering. Therefore, seed yield data need to be analyzed by considering two groups of genotypes separately, so as to separate the effects of phenology on salt stress tolerance from salinity tolerance *per se*. We also tested the hypothesis that the decrease in seed yield in the RIL was due to a decrease in seed number, rather than to a decrease in the 100-seed weight (which would measure seed filling), following the hypothesis that were made in 2007 using germplasm accessions. RILs that appeared to be tolerant maintained a larger relative seed number, whereas differences in seed filling did not explain the differences in seed yield.

This RIL population will again be phenotyped in 2007-08. To decrease the effect of earliness and expand a little the vegetative phase of early segregants, sowing was performed a little later (November), and a slightly higher salt treatment (125 mM) was used because the effect of 100 mM NaCl had induced a moderate reduction in seed

yield. Marker data for this population is also available and QTL mapping should start once we have the third set of phenotyping data.

V Vadez, L Krishnamurthy and PM Gaur

*Milestone: Mechanisms of tolerance to salinity characterized (VV/LK/NM) 2008*

We will test in detail 2 pairs of contrasting genotypes, having similar phenology, the effect of salt stress on the number of branches, flower buds, flowers, pods without seeds, pods with seeds, in plants treated by salt stress at sowing or at the time of flowering.

V Vadez and L Krishnamurthy

*Milestone: New RILs population for mapping of salinity tolerance QTLs developed (PMG/VV/LK) 2009*

**Development of RIL population for mapping QTLs for salinity tolerance:** Intra-specific RIL populations are being developed from two crosses, ICC 6263 (sensitive) x ICC 1431 (tolerant) and ICCV 2 (sensitive) x JG 11 (tolerant), for mapping QTLs for salinity tolerance. The F<sub>1</sub> from ICC 6263 x ICC 1431 were grown in the field during crop season 2006-07 and advanced by two generations in the greenhouse and rainout shelter during the off-season from April to September 2007 using single seed descent (SSD) method. About 300 F<sub>4</sub> RILs are being grown during 2007-08 along with the parents. Development of RILs from ICCV 2 x JG 11 was re-started as we lost seed of one of the original plants used in crossing. Crosses have been made and the F<sub>1</sub>s will be grown in crop season 2007-08.

PM Gaur, V Vadez and L Krishnamurthy

*Milestone: QTLs for salinity tolerance identified (VV/LK/RKV/PMG) 2009*

The phenotyping of JG 62 x ICCV 2 will be repeated in 2007-08. This population will tentatively be tested at Punjab Agricultural University, Ludhiana (India). Meanwhile, other populations are being advanced and their phenotyping is planned for 2009-10, when RIL will be at F<sub>8</sub> stage. In terms of molecular mapping, the parental genotypes ICCV 2 and JG 62 were screened with a total of 513 SSR markers, of which 326 yielded an amplicon that can be scored. Finally, 101 SSR markers showed polymorphism between these two genotypes. Identification of more polymorphic markers in this population is in progress.

V Vadez, L Krishnamurthy, PM Gaur and R Varshney

*Milestone: QTLs for salinity tolerance introgressed in farmer-preferred varieties (PMG/VV/LK/RKV) 2011*

Work will be initiated once the QTLs are identified.

Internal output target CP 6B.2: High throughput molecular genetic and phenotyping platforms for drought and salinity stress and promising transgenic events of chickpea for tolerance to drought stress available for commercialization and introgression in locally adapted germplasm

**Activity CP 6B.2.1: Develop and evaluate chickpea transgenic events for enhanced tolerance to drought stress**

*Milestone: 50 transgenic events of chickpea with DREB1A and P5CSF genes developed and screened for drought tolerance in the contained greenhouse (KKS/VV/PMG) 2007*

*Milestone: At least 8 promising transgenic events of chickpea containing DREB1A or P5CSF genes identified and their drought tolerance characterized under contained greenhouse conditions (KKS/VV/PMG) 2008*

*Milestone: Three promising transgenic events of chickpea identified for drought tolerance and characterized under contained field conditions (KKS/VV/PMG) 2009*

*Milestone: One or two transgenic events of chickpea used for introgression into locally adapted genotypes with better adaptation and the progeny characterized and evaluated (KKS/VV/PMG) 2010*

*Milestone: 10-15 introgressed transgenic lines of chickpea with improved tolerance to water-limiting conditions evaluated and development of commercialization package initiated (KKS/VV/PMG) 2011*



Genetic engineering of chickpea for enhanced tolerance to water stress is being carried out using the osmoregulatory *P5CSF129A* gene and *DREB1A* transcription factor that acts as a major “switch” that triggers a cascade of genes in response to a given stress. Forty-eight chickpea events with 35S: *P5CSF129A* and 18 events carrying *rd29A:DREB1A* were developed and advanced to subsequent generations. Southern analysis of the tested events indicated a low copy number (1-2 copies) in the 35S:*P5CSF129A* transgenics, whereas most of the events carrying *rd29A: DREB1A* had only a single copy of the transgene.

Previously, 10 transgenic events each of *rd29A:DREB1A* and 35S: *P5CSF129A* in T<sub>5</sub> generation were evaluated in drydown experiments, where the events exhibiting a diversity of stress response patterns, especially with respect to the normalized temperature ratio - fraction of transferable soil water (NTR-FTSW) relationship were selected from that ranking and comparative studies were carried out with these transgenics under optimized conditions for evaluating water use efficiency of the selected events. The transgenic events differed in response of NTR to FTSW, where their transpiration started declining at lower FTSW values (drier soil) under drought stress. This pattern was essentially the same for all events tested, as indicated by their lower FTSW threshold values. Besides, the physiological responses of the transgenic lines revealed a high photosynthetic activity (3.32-5.36) and stomatal conductance (0.0.29-0.71) under drought stress conditions as compared to the untransformed line (2.42; 0.037). These results indicated that although overexpression of osmolyte proline in the transgenic chickpeas resulted in a sort of osmotic adjustment by maintaining the cell turgor and physiological processes of these plants and resulting in postponement of dehydration as water deficits developed under the drydown conditions, however, there was no advantage in the TE values, which is one of the potential component traits of drought tolerance. The transpiration efficiency (TE) of only two transgenic events carrying 35S:*P5CSF129A* gene showed a modest increase in TE compared to the wild-type (WT) parent across experiments. On the other hand, several events carrying the *DREB1A* transcription factors driven by a stress-responsive promoter *rd29A* showed significant increase in transpiration efficiency compared to the WT.

Chickpea transgenics were assessed for over-expression of both *P5CSF129A* and *DREB1A* genes for water uptake and rooting pattern under water deficit in a lysimetric system, ie, long PVC tubing mimicking a field-like soil profile was done. Here, a more realistic physiological response to progressive soil drying has been proposed to include a proper control of soil moisture depletion so as to ensure that plants are exposed to stress levels and kinetics of water-deficits approaching those occurring under field conditions. The first experiment performed during the off-season did not show any particular advantage in the transgenics, and hence, will be repeated for the 2007-08 chickpea season under glasshouse conditions.

Seed multiplication and maintenance of desirable transgenic events in T<sub>5</sub> generation is being carried out and the plants are being characterized at molecular level to ascertain homozygosity. Additional events of chickpea carrying *rd29A:DREB1A* were being produced.

KK Sharma, P Bhatnagar-Mathur and V Vadez

## **Pigeonpea**

*Internal output target PP 6B.1: High throughput molecular genetic and phenotyping platforms and promising transgenic events for salinity tolerance in pigeonpea available for commercialization and introgression in locally adapted germplasm*

### **Activity PP 6B.1.1: Identify superior pigeonpea genotypes for salinity tolerance**

*Milestone: A set of pigeonpea genotypes suitable for breeding salinity tolerant breeding lines identified (VV/KBS) 2009*

Screening for salinity tolerance of wild and cultivated pigeonpea (mini-core collection plus few hybrids) was repeated in 2007. The trial has just been harvested and data are being processed. Attempts will be made to identify a set of contrasting pigeonpea genotypes, including both cultivated and wild type, which could be used in breeding.

V Vadez and L Krishnamurthy

### **Activity PP 6B.1.2: Develop intra- and inter-specific mapping population of pigeonpea between contrasting materials for salinity tolerance**

*Milestone: At least two mapping populations developed to map QTLs for salinity tolerance in pigeonpea (VV/KBS/NM) 2009*

*Milestone: QTLs for salinity tolerance identified in pigeonpea (VV/KBS) 2011*

Experiments involving contrasting pigeonpea genotypes for salinity tolerance, based on 2005 data, have been carried out to investigate the transpiration response to salt application. Basic consideration prior to undertaking that work was that salinity induces a drop in transpiration which may decrease photosynthetic rate and biomass accumulation. In such case, we can logically hypothesize that the “successful” genotypes would be the ones that are able to maintain a relatively high transpiration rate, and/or have high water use efficiency. Therefore, we studied: i) the relative reduction in transpiration rate of tolerant and sensitive genotypes, ii) the relation between water use efficiency and biomass accumulation under salt stress, and iii) the apparent xylem Na concentration in plants treated with salt.

The plants were grown under non-saline conditions in 20 cm diameter pots containing a mix of Alfisol and sand (1:1 w/w). At about 30 days after sowing, plants were saturated with water, allowed to drain overnight. The next morning, plants were bagged and weighed. Plants were weighed on day 1 and 2, so as to evaluate plant transpiration for 2 days. Then, half of the plants were treated with salt. On day 2, pots were saturated with 1500 ml of 37 mM salt and allowed to drain overnight. On day 3, plants were saturated with 1500 mL of 75 mM and allowed to drain overnight.

The decrease in transpiration was rapid after salt application. However, the relative transpiration rates continued to decrease steadily for the following 10 days, with several plants reaching less than 20% of control. One major finding was that tolerant cultivated pigeonpea genotypes (based on screening of 300 accessions), were all able to maintain a higher transpiration than the sensitive ones under salt stress. The same applied to wild pigeonpea accessions tested in that experiment, except for one. The results showed that the major effect of salinity on pigeonpea is to decrease transpiration steadily, resulting in a dramatic decrease in biomass accumulation. We also observed very little difference in TE under control conditions in most pigeonpea genotypes, except two wild *Alyosia* accessions that had higher TE. In contrast, salinity stress decreased TE dramatically. Decrease in dry weight under salt stress in pigeonpea was significantly correlated with water use efficiency ( $R^2 = 0.71$ ). We also observed large differences in the xylem Na concentration. Xylem Na in pigeonpea was higher than in groundnut. Wild relatives of pigeonpea had much lower xylem Na accumulation (24 - 45 mg Na kg<sup>-1</sup> water) than cultivated pigeonpea (43 - 105 mg Na kg<sup>-1</sup> water). Except for 2 genotypes that showed large variation in xylem Na concentration, there was a good relationship between the ratio of shoot biomass under salinity and the xylem Na concentration ( $R^2 = 0.51$ ).

V Vadez

**Output C: Knowledge of the improvements of the biotechnological and conventional tools designed to facilitate biofortification and biotransformation, breeding improved germplasm and pest management strategies of mandate crops and associated capacity building made available to partners internationally**

*MTP output target 2007 6.3.1 FORT: 75 transgenic events of groundnut with maize *psy1* gene developed and screened for high  $\beta$ -carotene production in the contained greenhouse (KKS/VA/SNN)*

**Output target 6C.1: High yielding and micronutrient dense hybrids/improved populations/varieties of sorghum and millet, and promising transgenic events of groundnut and pigeonpea with high beta-carotene content available for testing in national trials**

**Activity 6C.1.1: Develop groundnut transgenic events for enhanced production of beta-carotene**

*Agrobacterium*-mediated genetic transformation of groundnut was carried out using binary construct pCAMBIA 2300:Oleo-PSY1 for  $\beta$ -carotene enhancement in groundnut seeds. Ninety primary T<sub>0</sub> groundnut transgenic plants containing the maize phytoene synthase (*zmpsy1*) gene were established in the containment greenhouse for seed development and characterization. Molecular analysis of the primary (T<sub>0</sub>) transgenic events using PCR with gene-specific primers revealed the integration and presence of the *zmpsy1* in 75 out of the 90 events. Southern hybridization analysis using the gene-specific probes confirmed the integration of transgene in 20 out of 25 selected events. Transgene expression in the developing pods of groundnut was observed by RT-PCR analysis. The presence of mRNA transcripts of *zmpsy1* gene was observed in the selected plants. Seeds of T<sub>1</sub>

generation of the transgenics were collected from 80 events and 70 events were advanced to T1 generation in the containment greenhouse.

For the development of antibiotic marker-free groundnut transgenics, *zmpsy1* gene driven by the oleosin promoter was sub-cloned into the binary vector pPZP200 and mobilized into *Agrobacterium* strain C58. About 30 marker-free primary (T<sub>0</sub>) transgenic events of groundnut transformed with the binary construct 2300: *nptII* (minus *nptII* gene) were established in the containment greenhouse. Molecular analysis of the T<sub>0</sub> transgenic plants using PCR with gene specific primers (both *zmpsy1* junction and *nptII* primers) revealed the presence of only *psy1* gene in 23 out of 30 events. This showed an effective frequency of about 70% in the recovery of transgenic plants using marker-free system. Development of more marker-free transgenic events is in progress. For development of antibodies against phytoene synthase, the *zmpsy1* gene was cloned into pET expression vector. The over expression of PSY1 protein in *E. Coli* is being analyzed prior to its purification for the development of antibodies.

*Milestone: At least 8 promising transgenic events of groundnut containing maize psy1 gene identified and their stability characterized under contained greenhouse conditions (KKS/SNN) 2008*

Work on the identification of promising events are ongoing. Sixty out of 70 T1 generation transgenic events were molecularly characterized using PCR to study transgene inheritance, segregation, and expression in their progeny. Extraction and quantification of the total carotenoids and  $\beta$ -carotene in the primary transgenic seeds are in progress for the selection of best events. One of the major constraints in quantification of  $\beta$ -carotene in groundnut seeds is high lipid content that interferes in extraction of carotenoids. Different protocols for extraction and saponification are being optimized using  $\beta$ -carotene standard. In preliminary studies, orange yellow color carotenoids (including  $\beta$ -carotene) were extracted into groundnut oil and quantified using spectrophotometric measurements. The 40 transgenic events tested so far showed the enhancement of orange yellow color carotenoids ranging from 1 to 12  $\mu\text{g g}^{-1}$  seed. Extraction and quantification of  $\beta$ -carotene using HPLC in selected groundnut transgenic plants is in progress. Biochemical analyses are being planned with T<sub>2</sub> seeds, due to availability of a large sample size in the subsequent generations.

*Milestone: Three promising transgenic events of groundnut identified for high  $\beta$ -carotene production and characterized under contained field conditions (KKS/SNN) 2009*

Ongoing. The activities will follow from the milestone of 2008.

*Milestone: One or two transgenic events of groundnut with high beta-carotene content used for introgression into locally adapted genotypes and the progeny characterized and evaluated (KKS/SNN/RA) 2010*

Activities to be initiated after the identification of promising transgenic events.

*Milestone: 5-7 introgressed transgenic lines of groundnut with improved beta-carotene content evaluated and development of commercialization package initiated (KKS/SNN/RA) 2011*

Work not yet initiated.

KK Sharma, V Anjaiah and SN Nigam

*MTP output target 2007 6.3.2: 50 transgenic events of pigeonpea with maize psy1 gene developed and screened for high  $\beta$ -carotene production in the contained greenhouse (KKS/VA/KBS)*

#### **Activity 6C.1.2: Develop pigeonpea transgenic events for enhanced production of beta-carotene**

*Agrobacterium*-mediated genetic transformation was carried out using binary construct pCAMBIA 2300:Oelo-PSY1 for  $\beta$ -carotene enhancement in pigeonpea seeds. Over 140 primary T<sub>0</sub> pigeonpea transgenic events were established in the containment greenhouse for seed development and characterization. Molecular analysis on primary pigeonpea transformants (T<sub>0</sub> plants) using PCR with gene specific primers (both *zmpsy1* junction and *nptII* primers) revealed the integration and presence of the *zmpsy1* gene in 85 out of 142 events. Southern analysis using gene specific probes are being performed for confirmation of transgene in these events. RT-PCR analysis of the developing pods of pigeonpea is being carried out to observe the transgene expression in these events. Seeds of T<sub>1</sub> generation of pigeonpea transgenics were collected from 130 events to study the transgene inheritance, segregation, and expression in the progeny.

**Development of pigeonpea transgenic events for enhanced level of methionine:** For overproduction of methionine in pigeonpea seeds, Agrobacterium-mediated genetic transformation of pigeonpea was carried out using the binary construct pHS723:SSA containing sunflower seed albumin gene (*ssa*) driven by the vicillin promoter for seed-specific expression. Thirty-eight primary T<sub>0</sub> pigeonpea transgenic plants containing *ssa* gene were established in the containment greenhouse for seed development and characterization. Molecular analysis of primary pigeonpea transformants (T<sub>0</sub> plants) using PCR with gene specific primers (both *ssa* and *nptII* primers) revealed the integration and the presence of *ssa* gene in 32 out of 38 events. Southern analysis using gene specific probes is being performed for confirmation of transgene in these events. RT-PCR analysis of developing pods of pigeonpea is being carried out to observe transgene expression in these events. Seeds of T<sub>1</sub> generation of pigeonpea transgenics were collected from 30 events carrying *ssa* gene to study transgene inheritance, segregation and expression in these events.

*Milestone: At least 8 promising transgenic events of pigeonpea containing maize *psyl* gene identified and their stability characterized under contained greenhouse conditions (KKS/KBS/RKS) 2008*

Extraction and quantification of total carotenoids and  $\beta$ -carotene in primary transgenic seeds are in progress for the selection of best transgenic events. Total carotenoids (including  $\beta$ -carotene) were extracted in 120 out of 142 events and quantified using a spectrophotometer. Preliminary studies indicated the enhancement of total carotenoids in ten pigeonpea transgenic events. Extraction and quantification of  $\beta$ -carotene using HPLC in the selected pigeonpea transgenic plants is in progress. Biochemical analyses are being planned with T<sub>2</sub> seeds, due to availability of a large sample size in the subsequent generations.

*Milestone: Three promising transgenic events of pigeonpea identified for high  $\beta$ -carotene production and characterized under contained field conditions (KKS/KBS/RKS) 2009*

Activities towards this milestone are dependent on the milestone for 2008 (above).

*Milestone: One or two transgenic events of pigeonpea with high beta-carotene content used for introgression into locally adapted genotypes and the progeny characterized and evaluated (KKS/RKS) 2010*

Activities not yet initiated.

*Milestone: 5-7 introgressed transgenic lines of pigeonpea with enhanced beta-carotene content evaluated and development of commercialization package initiated (KKS/RKS) 2011*

Activities not yet initiated.

KK Sharma and V Anjiah

**Output target 6C.2: Transgenic groundnut with enhanced resistance to *Aspergillus flavus* and aflatoxin production identified and available for introgression into regionally adapted germplasm**

**Activity 6C.2.1: Develop and evaluate groundnut transgenic for enhanced resistance to *Aspergillus flavus***

*Milestone: Performance of the nine promising groundnut transgenic events expressing RChit gene for *A. flavus* resistance evaluated in contained on-station trials at ICRISAT, and best performing events identified (KKS/FW/SNN) 2007*

Genetic engineering approach was initiated to develop groundnut germplasm with durable resistance to *Aspergillus flavus*/*A. parasiticus* invasion in groundnut. The rice chitinase (RChi) gene under the control of the CaMV 35S promoter was introduced into a popular groundnut variety JL 24, using Agrobacterium tumefaciens-mediated genetic transformation by using the cotyledon explants from mature seeds. Twenty T<sub>1</sub> events carrying pCAMBIA 1302:RCH construct after preliminary characterization at DNA and RNA level were planted in P<sub>2</sub> glasshouse and bioassay carried out. Out of 20 T<sub>1</sub> events tested for fungal bioassay, ten events are showing resistance to LLS and rust as compared to control (for LLS, 19 lesions in transgenic and 190 lesions in control; and for rust 19 pustules in transgenic, and 500 pustules in control). Forty T<sub>1</sub> plants showing resistance in fungal bioassay were tested for chitinase activity. Out of 40 plants tested in T<sub>1</sub> generation, 8 plants showed higher chitinase activity (ranging from 0.4 to 1.6 units mg<sup>-1</sup> of protein) as compared to control (0.27 units mg<sup>-1</sup> of protein). Based on bioassays and chitinase assay results, progeny of five T<sub>2</sub> plants derived from 3 primary

transgenic events of JL 24 and progeny of five T<sub>2</sub> plants derived from 3 primary transgenic events of ICGV 89104 were planted in P<sub>2</sub> glasshouse. Fungal bioassay and molecular characterization of these events is undergoing. Besides these, 78 marker free transgenic events of JL 24 were developed using 2300 (-nptII): RCH construct. Eighteen events showed higher chitinase activity ranging from (0.43 to 3.89 units mg<sup>-1</sup> of protein) than the untransformed control (0.27 units mg<sup>-1</sup> of protein). Five events showing high chitinase activity were selected and planted in T<sub>1</sub> generation for carrying out the fungal bioassays.

Since we were not able to obtain the permission in time from Government of India, the promising groundnut transgenic events expressing RChit gene for *A. flavus* resistance were not planted, and the trial shall be planted in the next season.

*Milestone: At least 75 transgenic events of groundnut containing the peanut lipoxygenase (PNLOX13S) gene developed and characterized for gene integration and expression (KKS/FW/PLK/SNN) 2007*

To address the issue of resistance to aflatoxin production in groundnut, a 13S-lipoxygenase (13S-LOX) gene from groundnut is being used in collaboration with Prof. Nancy Keller of University of Wisconsin, USA. The 13S-LOX gene has been cloned into a binary vector (pPZP100) for marker-free production of transgenic plants. *Agrobacterium tumefaciens*-mediated genetic transformation with the plasmid pZP100:13SLOX has been initiated by using the cotyledon explants from mature seeds of the groundnut variety JL 24.

*Milestone: Ten promising transgenic events of groundnut with PNLOX13S identified for enhanced resistance to aflatoxin production under contained greenhouse conditions (KKS/FW/PLK/SNN) 2009*

The outputs from milestone of the year 2008 will lead to the activities here.

*Milestone: Five promising transgenic groundnut events with PNLOX13S identified and disease resistance characterized under contained field conditions (KKS/FW/PLK/SNN) 2010*

Activities not initiated at this time.

*Milestone: Two best transgenic groundnut events with resistance to A. flavus used for introgression into locally adapted groundnut genotypes and their evaluation (KKS/FW/PLK/SNN) 2011*

Activities not initiated at this time.

KK Sharma, F Waliyar and SN Nigam

### **Output target 6C.3: Simple and cost-effective test for the estimation of mycotoxins (Aflatoxins, Fumonisin and Ochratoxin-A) in crops and commodities, and aflatoxin-adducts in human serum developed and validated**

*MTP output target 2007 6.3.1 DTOX: Enzyme-linked immunosorbent assay (ELISA) developed for the estimation of aflatoxin adducts in human serum (FW)*

#### **Activity 6C.3.1: Develop a diagnostic test to determine the human exposure to aflatoxins**

Aflatoxin is produced as a secondary metabolite of the fungus *Aspergillus flavus*. Consumption of aflatoxin contaminated food forms the aflatoxin-lysine adducts in human blood and leads to the liver damage. Frequent exposure to aflatoxin increases the risk of liver cancer. Since aflatoxin-lysine adduct in blood can be detected upto 20- 30 days, detection of aflatoxin –lysine adduct in blood serves as a biomarker. Several physico-chemical methods are available for detection, however, we have developed ELISA based technology for detection of aflatoxin in human blood. This method was used to analyze blood samples from people affected with liver related diseases. About 80 blood samples were collected from the Asian Institute of Gastroenterology, Hyderabad (India) along with samples information on their food habit and clinical status. Patients were selected based on clinical diagnosis and were grouped as: patients with liver cirrhosis, chronic liver disease, hepatitis B, hepatitis C, alcoholic liver disease, non alcoholic liver disease, liver cirrhosis with hepatitis B, liver cirrhosis with hepatitis C, hepatocellular carcinoma, chronic liver disease with hepatitis B/ hepatitis C. Their food habits including people eating more peanut, maize, rice, chilies, source of food, their socio-economic status were surveyed. The blood samples were collected and serum was separated and brought to ICRISAT-Patancheru in dry ice.

To extract aflatoxin from the blood samples, first the albumin was separated from serum of the blood samples and digested with the protease-K enzyme, followed by ELISA. Among 80 samples, 50% of the samples were free from the toxin and the remaining samples were positive for aflatoxin with the range 6 - 212  $\mu\text{g mg}^{-1}$  of the albumin. Among the aflatoxin positive samples, 45 were from patients having either hepatitis B or hepatitis C, and/or with liver disease. The result indicated there is a high risk for liver cancer when hepatitis B combines with aflatoxin. In another study, we collected 165 blood samples randomly, and ELISA result indicated that there was no aflatoxin positive among these people, and all of them were free from the aflatoxin adduct. This study provides the scope for preventive interventions in persons at high risk of liver cancer. A publication on detection methodology and the data obtained from different groups of liver diseases patients is being prepared.

F Waliyar and P Lava Kumar

### **Activity 6C.3.2: Develop simple and cost-effective assays for the detection of mycotoxins in crops and commodities**

*Milestone: Simplified ELISA-based assay for the detection of mycotoxins developed (FW) 2007*

**ELISA based assay for detection of mycotoxins:** Aflatoxin contamination is widespread in staple crops like groundnut, maize, cassava, etc, and compromises the safety of food and feed. It is important to be able to detect and quantify aflatoxins in commodities to protect human and animal health. Different methods, including antibody-based ones, are available for quantitative estimation of aflatoxins. However, most of these methods are expensive and/or difficult to use in developing countries. Using the state-of-the-art facilities at ICRISAT, we developed polyclonal and monoclonal antibodies for the detection of total aflatoxins, aflatoxin B1 and M1 (secreted in milk). These were used to develop a simple and inexpensive competitive enzyme-linked immunosorbent assay (cELISA) that has lower detection limit of 2.5  $\mu\text{g kg}^{-1}$ , and is the cheapest in the world.

Current efforts are focused on developing simple and inexpensive on-site screening test for aflatoxin estimation. To simplify the technique, the combinations of coating ABB1-BSA and antibody concentration at various dilutions to reduce the detection time and to improve the precision of the test were studied. By increasing the AFB1-BSA coating concentration and antibody dilution, we can reduce the detection time from the existing 4 h to one hour. However, it's a skillful exercise and needs further confirmation. We also developed strategies to reduce the cost of sample analysis by using border rows of the ELISA plate and reducing (50%) the sample weight, which in turn reduces the chemical consumption. These tests have provided a unique opportunity for ICRISAT and its partners to conduct field studies to identify high risk populations and determine dietary sources to stimulate appropriate interventions to enhance food and human health safety and trade, thereby the farmers' income. The diagnostic reagents were widely distributed to partners in Asia and SSA. ICRISAT helped in setting up of 16 aflatoxin monitoring laboratories in India, Mozambique, Kenya, Malawi and Mali that uses our ELISA technology. These laboratories are contributing to the quality certification of the farmers' produce and enhances the competitiveness of the produce in domestic and international markets. For instance, the aflatoxin laboratory in Malawi contributed to the revival of groundnut exports to Europe and South Africa.

F Waliyar and P Lava Kumar

*Milestone: Tube/filter paper based semi-quantitative immuno assay developed for the on-site detection of aflatoxins (FW/PLK) 2008*

Yet to start the work on this.

F Waliyar

*Milestone: Multiplex filter paper immuno assay developed for the rapid estimation of aflatoxins and fumonisins (FW/PLK) 2009*

Yet to start the work on this.

F Waliyar

*Internal output target 6C.4: Aflatoxin resistant/tolerant groundnut genotypes identified*

### **Activity 6C.4.1: Evaluate groundnut varieties for resistance to *Aspergillus flavus* and aflatoxin production by in vitro inoculation studies and on-station testing in sick fields**

*Milestone: 10-15 new high yielding, aflatoxin resistant lines identified and made available to NARS (RA/SNN/FW) Annual*

We evaluated 134 F<sub>2</sub>-F<sub>7</sub> bulks and 3 single plants in 2006/07 post-rainy season for agronomic performance. From these, 127 bulks and 211 single plants were selected for further evaluation. The promising selections came from ICGV 01031 x ICGV 14985 and ICGV 95469 x ICGV 01133. During the 2007 rainy season, 338 F<sub>2</sub> – F<sub>8</sub> selections were sown for evaluation. From these, 204 bulks and 180 single plant selections were made. Promising selections (12) came from (ICGV 93291 x ICGV 01002), (ICGV 95469 x ICGV 01031), (ICGV 01031 x ICGV 14985), (ICGV 95469 x ICGV 01133) and (ICGV 93280 x ICGV 01092). We also evaluated 138 advanced breeding lines (including controls) in 5 replicated trials in the 2006/07 post-rainy season for agronomic performance. We also evaluated 110 advanced breeding lines (including controls) in 3 replicated trials in the 2007 rainy season. Analysis of trial data for the 2007 rainy season is in progress. All the entries in replicated trials were also grown in an *Aspergillus flavus* sick plot to record observations on seed infection by *A. flavus* and aflatoxin production.

In Elite Trial (Spanish), ICGV 03401 (5.5 t ha<sup>-1</sup> pod yield and 99.37 µg kg<sup>-1</sup> aflatoxin production) significantly out-yielded the best susceptible control ICGV 11 (4.6 t ha<sup>-1</sup>, 22.38 µg kg<sup>-1</sup>) and resistant control J 11 (4.3 t ha<sup>-1</sup>, 78.90 µg kg<sup>-1</sup>). In Elite Trial (Virginia), five entries (5.8 - 4.6 t ha<sup>-1</sup> pod yield) significantly out-yielded the best susceptible control ICGV 11 (4.8 t ha<sup>-1</sup> pod yield, 312.27 µg kg<sup>-1</sup> aflatoxin production) and resistant control J 11 (3.4 t ha<sup>-1</sup>, 37.64 µg kg<sup>-1</sup>). ICGV 03370 produced highest pod yield (5.8 t ha<sup>-1</sup>, 715.25 µg kg<sup>-1</sup>) followed by ICGV 03377 (5.3 t ha<sup>-1</sup>, 229.85 µg kg<sup>-1</sup>). In Advanced Trial-1, four entries (6.7 - 6.0 t ha<sup>-1</sup> pod yield) significantly out-yielded the best resistant control J 11 (4.6 t ha<sup>-1</sup> pod yield, 0.86 µg kg<sup>-1</sup> aflatoxin production). ICGV 03370 produced highest pod yield (6.7 t ha<sup>-1</sup>, 0.96 µg kg<sup>-1</sup>), followed by ICGV 04050 (6.3 t ha<sup>-1</sup>, 0.84 µg kg<sup>-1</sup>). In Advanced Trial-2, eleven entries (6.4-5.7 t ha<sup>-1</sup> pod yield) significantly out-yielded the best susceptible control ICGV 11 (4.6 t ha<sup>-1</sup> pod yield, 79.88 µg kg<sup>-1</sup> aflatoxin production) and resistant control J 11 (3.6 t ha<sup>-1</sup>, 11.56 µg kg<sup>-1</sup>). The most promising entries were ICGV 06346 (6.3 t ha<sup>-1</sup>, 52.28 µg kg<sup>-1</sup>), ICGV 06347 (6.0 t ha<sup>-1</sup>, 8.00 µg kg<sup>-1</sup>), ICGV 06370 (5.9 t ha<sup>-1</sup>, 4.24 µg kg<sup>-1</sup>), ICGV 06335 (5.9 t ha<sup>-1</sup>, 5.22 µg kg<sup>-1</sup>), and ICGV 06369 (5.7 t ha<sup>-1</sup>, 4.37 µg kg<sup>-1</sup>). In Advanced Trial-3, three entries (6.1-5.6 t ha<sup>-1</sup> pod yield) significantly out-yielded the best susceptible control ICGV 11 (4.5 t ha<sup>-1</sup> pod yield, 94.07 µg kg<sup>-1</sup> aflatoxin production) and resistant control J 11 (3.6 t ha<sup>-1</sup> pod yield, 2.34 µg kg<sup>-1</sup> aflatoxin production). ICGV 06409 produced highest pod yield (6.1 t ha<sup>-1</sup>, 1.87 µg kg<sup>-1</sup>), followed by ICGV 06408 (5.7 t ha<sup>-1</sup>, 2.34 µg kg<sup>-1</sup>).

SN Nigam, R Aruna and F Waliyar

*Milestone: Preliminary, advanced and elite foliar disease resistant breeding lines evaluated for resistance to A. flavus and aflatoxin production under artificial inoculation conditions in the field and at least 5 resistant varieties identified for commercialization (FW/SNN/RA) 2009*

**Screening of advanced breeding lines for resistance to *Aspergillus flavus*:** During 2006 rainy and 2006-07 post-rainy seasons, 167 advanced breeding lines (including checks) were evaluated for their resistance to *A. flavus* seed infection and aflatoxins contamination. The lines were divided into seven trials, and tested in six replications. The test materials were planted in the sick plot; *A. flavus* inoculum multiplied on sorghum or maize seed was applied in the soil near to the groundnut plants. The inoculum was applied 4 - 5 times at about 10-day intervals during the crop growth period and end of season drought was imposed 30 days before harvest to facilitate the seed infection. Harvesting was done by uprooting the plants and the produce was dried for 2 - 3 days under natural sunlight. Pods from each plot were collected separately, shelled manually, and kernel sub-samples were taken for *A. flavus* seed infection using blotter plate method and aflatoxin contamination by indirect competitive ELISA method. *Aspergillus flavus* infection and aflatoxins contamination in test lines ranged from 0 to 69% and 0 to 3128 µg kg<sup>-1</sup> respectively. All the 20 elite lines representing Spanish bunch, Virginia bunch and Dark green leaf materials showed >10 µg kg<sup>-1</sup> aflatoxin, and most of the lines had <5% *A. flavus* seed infection. ICGV 04036 showed <10 µg kg<sup>-1</sup> aflatoxin; among 49 AAFRGVT-2 varieties, eight lines (ICGV nos. 06336, 06338, 06340, 06347, 06360, 06362, 06363 and 06370) were less susceptible to *A. flavus* seed infection (<5%) and aflatoxin contamination (<10 µg kg<sup>-1</sup>); and 10 of the 49 AAFRGVT-3 genotypes (ICGV 06371, 06375, 06377, 06383, 06384, 06396, 06400, 06406, 06407 and 06415) showed <5% seed infection and <10 µg kg<sup>-1</sup> aflatoxin contamination. For the past several years, we have been observing that *A. flavus* seed infection and aflatoxin contaminations were higher in post-rainy season than in the rainy season. Hence, all the breeding materials will be tested in the AF sick plot only in the post-rainy season.

F Waliyar, SN Nigam, P Lava Kumar and R Aruna

*Milestone: Ten interspecific derivatives of groundnut evaluated for A. flavus and aflatoxin resistance and promising lines identified (FW/NM) 2010*

**Evaluation of progenies from crosses of wild Arachis:** We have tested 60 progenies from wide hybridization crosses by AF artificial inoculation method, and identified five progenies (event nos. 2929-6, 2929-15, 4367-3, 4368-7 and 4373-15) that showed 7 - 10% infection/colonization. Healthy seed from all the progenies were retrieved and used for planting in the sick plot for further testing in the field. Since seed from the field grown material was not sufficient for *A. flavus* seed infection and aflatoxin contamination, we tested five promising progeny lines for seed infection by blotter test method and observed that only 4373-15 progeny was susceptible (>10%) to seed infection, while the remaining four lines showed <3% infection. One promising (4368-7) and one susceptible (18-3) line were selected to see the cotyledon resistance for aflatoxin production. Seedcoat was damaged before inoculation with *A. flavus* for these two progenies along with susceptible (JL 24) cultivar, and it was found that both the lines showed >80% seed infection and produced >15,000 g kg<sup>-1</sup> aflatoxin. The progenies planted in the sick plot during 2007 rainy season were harvested and are being analyzed.

F Waliyar

*Milestone: Multilocational trails of five A. flavus resistant/low aflatoxin producing interspecific derivatives conducted in target locations in India (FW/NM/RA) 2012*

This work is yet to start.

F Waliyar

#### **Activity 6C.4.2: Evaluate various soil amendments and biocontrol agents for reducing pre-harvest *A. flavus*/ aflatoxin contamination in groundnut**

*Milestone: Efficacy of Pseudomonas and Actinomycetes in preventing pre-harvest aflatoxin contamination determined (FW) 2008*

Studies were carried out in vitro to isolate new biocontrol agents such as *Pseudomonas* and *Actinomycetes* for the control of pre-harvest *A. flavus* infections and aflatoxin contamination. About 64 bacteria and 40 *Actinomycetes* were isolated from rice straw compost and were preserved for future use. The bacterial isolates were numbered with a prefix CDB and *Actinomycetes* isolates were numbered with prefix CDA. All these isolates were evaluated for their antagonism against *A. flavus* in vitro using double layer method on Glucose Casamino acid Yeast extract medium (GCY). Out of these, seven *Actinomycetes* and 17 bacteria significantly inhibited *A. flavus* growth under plate culture conditions. The fungal strain used in our studies is AF 11-4, which is highly virulent and highly toxigenic. The isolated bacteria and *Actinomycetes* are being characterized for their plant growth promoting traits, antagonism under field conditions, and against other soil borne phytopathogenic fungi.

F Waliyar

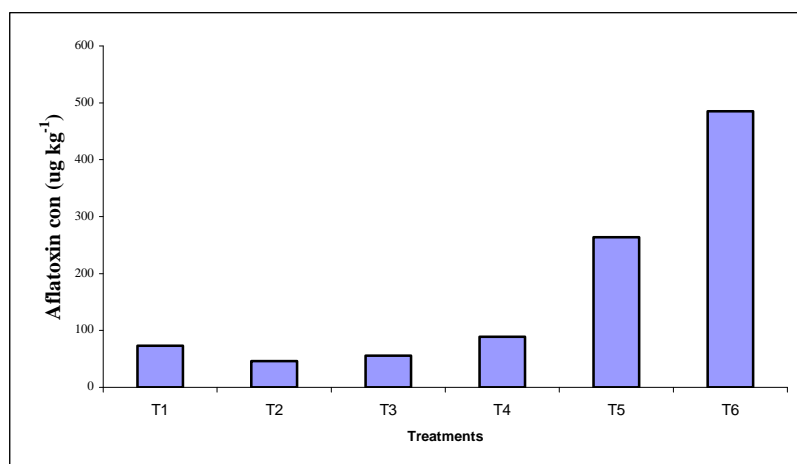
*Milestone: Integrated management package using various soil amendments and biocontrol agents, for preventing pre-harvest aflatoxin contamination developed (FW) 2009*

A field experiment was laid out in a completely randomized block design using groundnut variety, JL 24 in two planting dates so as to see the differences in colonization of *A. flavus* in rainy and postrainy seasons. Bacteria (CDB 35) field experiment was conducted with six treatments and six replications (T1 = seed coating with CDB35, T2 = seed priming with CDB 35, T3 = seed priming with CDB 35 + *Rhizobium* (IC 7114), T4 = Compost + CDB 35, T5 = Control compost, T6 = control). *Actinomycetes* (CDA 19) field experiment was conducted with six treatments and six replications. (T1 = seed coating with CDA 19, T2 = seed priming with CDA 19, T3 = seed priming with CDA 19 + *Rhizobium* (IC 7114), T4 = compost + CDA 19, T5 = control compost, T6 = control).

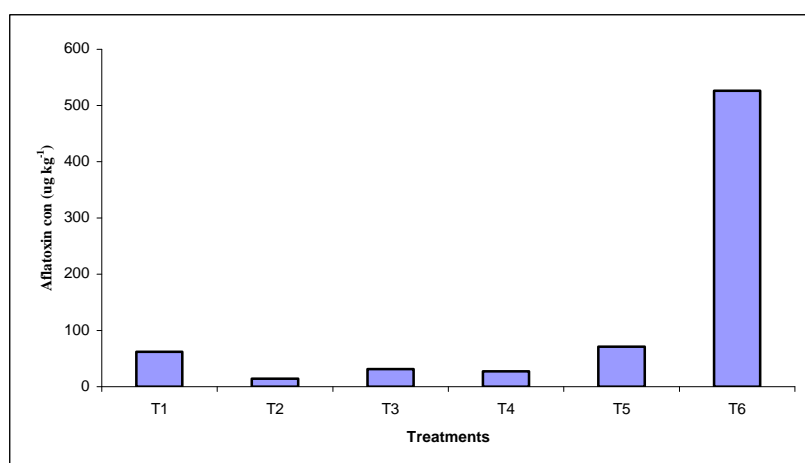
Seed samples from each plot were analyzed for *A. flavus* seed infection using blotter plate method and aflatoxin content by indirect competitive ELISA method. *Aspergillus flavus* infection was low in the treatments with *Pseudomonas* sp. (CDB 35) which ranged between 0.2 - 0.7% compared to control (4%). In the field inoculated with *Actinomycetes* (CDA 19), infection ranged between 0.3 - 0.8% compared to control (2.7%). Significant reduction in aflatoxin content was observed in both the experiments. With bacteria CDB35 application, overall reduction ranged between 54 – 91% across the treatments with 91% reduction in the treatment with seed priming, followed by seed priming with CDB 35 + *Rhizobium*, which was 89% (Fig. 7). With *Actinomycetes* (CDA19), 98% reduction was observed in seed priming treatment with CDA 19, followed by seed priming



together with Rhizobium, which was 95%. Overall reduction ranged between 90 - 98% across treatments (Fig. 8).



**Figure 7. Effect of bacterial biocontrol agent (CDB 35) application on aflatoxin in various treatments during field experiment in 2006 rainy season.**



**Figure 8. Effect of actinomycets (CDA 19) application on aflatoxin in various treatments during field experiment in 2006 rainy season.**

F Waliyar

*Internal output targets 6C.5: Effective and eco-friendly IPM technologies designed, evaluated and shared for the management of insect pests*

**Activity 6C.5.1: Impact of the village-wide bio-pesticide production on the effective implementation of IPM**

*Milestone: Impact of village level biopesticide production and utilization documented (GVRR) 2007*

*Milestone: Mass production techniques and stable formulations developed (GVRR/OPR) 2009*

**Production and utilization of HNPV at village level:** Nearly 201 researchers from NARS, and 983 farmers in India and Nepal, were trained in NPV production, with special emphasis on importance of residue-free food. High priority was given to technology dissemination of an eco-friendly approach with the active participation of all partners at various locations. This also provided an opportunity to strengthen the eco-friendly activities by establishing bio-pesticide units in 96 villages in India and Nepal. These village units produced 500 - 20,000

larval equivalents (LE) of the virus, and utilized it on a number of crops including cotton, vegetables, chickpea, and pigeonpea with satisfactory results. Through the awareness created in the project sites, there was a significant reduction in application of chemical pesticides by 65% in cotton, 24% in pigeonpea and 21% in chickpea, resulting in savings in inputs and increased population of crop-friendly insects. The crop samples analyzed for pesticide residues in 15 participating (41 samples) and 5 non-participating (15 samples) villages revealed the presence of pesticide residues in 21 samples above 0.001 ppm. However, one sample each of Dolichos and tomato had residues of monocrotophos (0.697 ppm) and chlorpyriphos (0.126 ppm) above maximum residue limits (MRL) of 0.1 ppm prescribed by FAO.

GV Ranga Rao

### **Activity 6C.5.2: Develop technologies for production, storage and utilization of entomopathogenic strains of NPV, bacteria, fungi and botanicals with insecticidal properties**

*Milestone: Virulent strains of entomopathogenic NPV, bacteria, fungi and botanicals with insecticidal properties identified (GVRR/OPR/HCS) 2007*

*Milestone: Rural stakeholders trained in biopesticide production and utilization and relevant rural enterprise initiated (OPR) 2009*

**Role of biopesticides in IPM:** Practitioners of organic farming were noted to successfully manage their crops without synthetic pesticides. Interactions with a large number of farmers indicated that botanicals and some locally prepared ferments played a major role in crop protection at their farms. These products and practices along with entomopathogenic microorganisms were considered adequate for managing crop pests. Focus of our work was on: a) articulating science to farmers' knowledge, and b) developing marketable low-cost but effective microbial products and botanicals for SAT farmers, in partnership with private and public-sector companies. A 5-year account of progress made on this activity in general, and on this milestone in particular, is given below.

Over 1,000 cultures were isolated as part of a drive to access, from natural niches, agriculturally beneficial microorganisms representing six different traits—cellulose degradation, nitrogen fixation, P-solubilization, plant growth promotion, antagonism to disease-causing fungi and pathogenicity to insect-pests. All these had at least one such trait as judged by their growth on specific plate-culture media or represented diversity in a given natural niche, and thus, formed part of a preliminary culture collection for further studies. Two hundred and eighteen of these were screened in lab conditions for efficacy to kill larvae of *Helicoverpa* and/or *Spodoptera* in different batches. Thirty-eight cultures were noted as promising (killed 50 to 88 % neonate larvae). Three of seven that were evaluated also had the ability to enhance plant growth in glasshouse studies.

Different published recipes for insect rearing generally had antibiotics as one of the components. This potentially interfered with survival and performance of microbial agents. We therefore modified the recipes and deleted antibiotics. Experience indicated that most biopesticides (including some commercially available products) took a long time to kill 3<sup>rd</sup> instar larvae, and were essentially ineffective on large sized larvae. Therefore, neonates were used in screening of different cultures for pathogenicity.

Five hundred and ninety-five cultures from the collection were screened for ability to form spores. One hundred and seventy-nine of these were noted positive, and belonged to *Bacillus* spp. All these were stained for crystal protein and observed under microscope. Only seven were found positive, and thus, highly likely are *Bacillus thuringiensis*. Confirmation studies are planned using molecular biology methods.

Thirty-one botanicals were evaluated in lab conditions for ability to kill larvae of *Helicoverpa* and/or *Spodoptera*. Eight of these performed similar to or better than commercially available neem oil (1% in water). Ten of the fourteen that were studied, repelled *Spodoptera* moths as judged by reduced egg-laying on liners treated with these materials compared to control, when studied in oviposition chambers. Details of these studies are available in reports/theses written by eight apprentices/research scholars, who worked in Biocontrol Laboratory (2003 to 2007). Inconsistency in performance of a given material from batch to batch was noticed, both in the case of microorganisms and botanicals, and remains a major concern. Materials showing a strong tendency of repeatability were advanced for further studies and are reported here. Stage of growth and growth medium used in the case of microbial agents, and age of botanicals, were considered the likely reasons for inconsistency. Also, we rarely saw more than 80% mortality by any material evaluated so far. In field studies, sucking pests were important after the lepidopterans. Finding solutions to them is equally challenging. Only six promising microbial cultures were evaluated in field conditions in different years for their ability to manage

such insect-pests. *Bacillus subtilis* BCB19 in studies during 2003/05 and SB19 (probably *B. mycoides*) during 2005/06 performed at par with commercially available Bt formulation and/or the treatment receiving synthetic pesticides.

A best-bet protocol involving crop management, botanicals, and microbial agents was evaluated on-farm at Kothapally and Yellakonda in Rangareddy district, Andhra Pradesh, India. Each partner farmer was required to divide a given field into two halves, one side protected using ongoing practices (Farmer Practice or 'FP'), using synthetic pesticides, and the other side using low-cost and biological options for crop protection (Biological Options or 'Bio'). Results of this on-going study suggested that the crops were effectively protected in 'Bio' plots for four years in case of cotton (during 2003/04 to 2006/07) and three years (summers of 2004 to 2006) in the case of vegetables (largely tomato). Crop yields were higher in 84 out of 110 events in the case of cotton, and in 27 out of 30 events in the case of vegetables. As a part of the agreement, all the partner farmers are charged for the cost of biopesticides them at the rate of Indian Rupees 1700/- (1US\$ = Indian approx. Rupees 40) per ha, and advice provided to, suggesting confidence of the farmers in the protocol.

With this report the milestone is considered as reached. Future studies will focus on identifying more botanicals with ability to manage sucking pests and repel moths of *Helicoverpa* and/or *Spodoptera*, and more microbial agents with ability to produce spinosad or avermectin-like metabolites. The studies will also focus on: a) mass multiplication of microbial cultures and new formulations to reduce grammage without compromising efficacy, b) accessing microbial entomopathogens from new natural niches not explored so far, c) further testing of the best-bet protocols for crop protection involving only low-cost and biological options, both at research station and on-farm. Some botanicals and microbial agents were noted to suppress disease-causing fungi. All promising materials will be evaluated, and the information used in selecting agents for mass-scale production and field use.

OP Rupela

*Milestone: Botanicals with ability to kill insects having compatibility with entomopathogenic microorganisms identified and appropriate delivery systems developed (OPR/GVRR) 2008*

**Evaluation of botanicals with insecticidal properties:** Ten indigenous plant materials (*Cleistanthus collinus*, *Calotropis gigantea*, *Pongamia glabra*, *Sphaeranthus indicus*, *Cassia occidentalis*, *Chloroxylon swietenisia*, *Vitex negundo*, *Madhuca indica*, *Strychnos nuxvomica*, *Strychnos pototorum*) known for insecticidal properties collected from Andhra Pradesh and Chhattisgarh (India) were evaluated against *Helicoverpa armigera* larvae. The water extracts of these products against second-instar larvae clearly indicated the superiority of *Cleistanthus collinus*, and *Sphaeranthus indicus* with 57% larval mortality one week after exposure. Though the other plant products were inferior in their insecticidal properties, 48% larval mortality was observed in *Chloroxylon swietenisia*, 37% in *Calotropis gigantea* and *Strychnos nuxvomica*, 30% in *Pongamia glabra* and *Madhuca indica*, 23% in *Strychnos pototorum*, 13% in *Vitex negundo*, and 10% in *Cassia occidentalis*. Further observations on larval mortality two weeks after exposure revealed similar trend (range of 17 - 63%). Maximum mortality was observed in *Cleistanthus collinus* and *Sphaeranthus indicus* (63%) and were superior to other plant extracts. Since these botanical extracts have shown encouraging results, their potential needs to be evaluated further under laboratory and field conditions to utilize them as one of the options in integrated pest management programs.

GV Ranga Rao

### **Activity 6C.5.3: Develop strategies for deployment of insect resistant cultivars/transgenic crops for pest management and their bio-safety to non-target organisms**

*Milestone: Compatibility of host plant resistance with natural enemies and insecticides studied (HCS/MKD) 2010*

**Influence of temperature and insect host on survival and development of *Helicoverpa armigera* parasitoid, *Campoletis chloridae*:** The ichneumonid endoparasitoid, *Campoletis chloridae* is an important natural enemy of legume pod borer, *Helicoverpa armigera* in different agro-ecosystems. Environmental factors and nutritional quality of the insect host influence the activity and effectiveness of natural enemies. The present studies were conducted to understand the influence of temperature on development and survival of the parasitoid, *C. chloridae*. Temperatures <12°C and >35°C were detrimental to the parasitoid, *C. chloridae* larval development and survival. Post-embryonic development of *C. chloridae* had a significant and negative association with temperatures between 18 and 27°C. The parasitoid took 2.5-fold more time to complete development at 18°C than at 27°C. Parasitization and adult emergence were significantly influenced by food,

parasitoid age and temperature. Longevity of *C. chlorideae* adults was negatively associated with temperature. The sex ratio of the insects reared at 12°C was male biased, while on those reared at 27°C was female biased. The results indicated that temperature exercises considerable influence on development, survival, fecundity and sex ratio of the parasitoid, *C. chlorideae*, and this information will be useful for developing strategies for biological control of *H. armigera*.

HC Sharma and MK Dhillon

Economic thresholds for *Helicoverpa armigera* in pigeonpea: We evaluated the effect of different protection regimes for management of *H. armigera* on two genotypes of pigeonpea (ICPL 332 and ICPL 87119) to assess economic thresholds of this pest on different genotypes. The plots were sprayed at 10 and 75% flowering, 50% podding and dough stages in different combinations. There were three replications in a RCBD for each variety. Untreated plots served as a control. Data were recorded on oviposition, larval density, pod damage and grain yield. There were no significant differences in egg and larval numbers in plots receiving different levels of protection, except in larval numbers at the dough stage in ICPL 87119. Pod damage was 89.2 to 100% in ICPL 87119 and 92.7 to 100% in ICPL 332 in untreated control plots and those sprayed at 10 and 75% flowering stages. Pod damage was 43.3 and 30.8% in ICPL 87119 and 40.1 and 44.9% in ICPL 332 in plots sprayed 3 and 4 times, respectively. Grain yield was 171.7 and 119.3 kg ha<sup>-1</sup> in untreated plots and those sprayed at the 10% flowering stage only, compared to 1182.3 and 1327 kg ha<sup>-1</sup> in plots sprayed 3 and 4 times, respectively, in ICPL 87119. In ICPL 332, the grain yield varied from 193.7 to 1200 kg ha<sup>-1</sup>. There were no apparent differences in the response of these two genotypes for *H. armigera* control in combination with insecticides.

HC Sharma

*Milestone: Compatibility of transgenic crops and insecticides for pest management and their impact on species diversity assessed (HCS/MKD/KKS) 2012*

**Role of Bt-transgenic cottons in management of *Helicoverpa*, and their effects on non-target natural enemies and toxin flow in insect fauna:** Five experimental hybrids including bollguard II (with two *Bt* genes) were planted under protected and unprotected conditions to monitor the impact of transgenic and non-transgenic cottons and insecticide application on economically important insect pests of cotton and their biocontrol agents. A total of 36 insect species were collected, and tested for the presence of *Bt*-toxin using qualitative ELISA. Amongst these, *Clubiona* sp., short horned grasshopper, green grasshopper, *Blissus* sp., *Dysdercus koenigii*, *Mylocerus* sp., *Amrasca bigutulla bigutulla*, *Thrips tabaci*, *Chrysoperla* sp. larvae, and one katydid species had high levels of *Bt* toxin (>5.0 ppb), while *H. armigera* larvae and coccinellids, *C. sexmaculatus* adults and larvae showed moderate (2.5 to 5.0 ppb) levels of *Bt*-toxins. There was no variation in numbers of arthropod species in transgenic and non-transgenic cottons.

HC Sharma and MK Dhillon

*Milestone: Bio-safety of transgenic crops to nontarget organisms assessed (HCS/KKS) 2015*

**Direct effects of *Bt* toxins on coccinellids predators:** Trypsin activated (95% pure) *Bacillus thuringiensis* (*Bt*) proteins Cry1Ab and Cry1Ac, were bio-assayed against two predatory coccinellids, *Cheilomenes sexmaculatus* and *Adalia bipunctata*. Proteins were dissolved in a 2M sucrose solution at a concentration of 0.1%. Bioassays were conducted with freshly neonate *C. sexmaculatus* and *A. bipunctata* larvae, which were kept individually in bioassay cups (3.3 cm diameter, 3.5 cm depth), and fed on pure 2M sucrose solution, or a 2M sucrose solution containing 0.1% Cry1Ab or Cry1Ac *Bt* proteins. The larvae were provided the aphid host, *A. craccivora* every 24 h. One set of each of *C. sexmaculatus* and *A. bipunctata* larvae were continuously fed on *A. craccivora*. There were 30 replications for *C. sexmaculatus* and 10 replications for *A. bipunctata* in a completely randomized design. The observations were recorded on different life table parameters. There were significant differences in larval period, larval weight and survival, larval and pupal periods, and adult emergence. The larval and pupal periods were prolonged in insects fed on sucrose solution containing Cry1Ab (9.1 days) and Cry1Ac (9.3 days) as compared to those fed on sucrose alone or aphids alone. The larval weights were significantly lower in insects fed on diets containing *Bt* proteins as compared to those fed on sucrose or aphids alone. Similar was the trend for adult female weight. Larval survival and adult emergence were significantly lower on diets containing Cry1Ab as compared to those fed on Cry1Ac, 2M sucrose, or aphids alone, suggesting some adverse effect of Cry1Ab on the predatory coccinellids.

**Indirect effects of *Bt*-transgenic and non-transgenic cotton hybrids on survival and development of *Helicoverpa armigera* larval parasitoid, *Camponotus chlorideae*:** Effects of *Bt*-transgenic (two hybrids expressing *cry1Ac*, and one expressing *cry1Ab* and *cry1Ac* genes) and the non-transgenic cotton hybrids on

ichneumonid parasitoid, *C. chloridae* were studied under greenhouse conditions through *H. armigera* larvae fed on leaves of 75 days old cotton plants. The *C. chloridae* took 2.6 days longer to complete post-embryonic development on *Bt* Mech 184 fed *H. armigera* larvae than on non-*Bt* Mech 184. Survival of the parasitoid was significantly lower on *Bt* Mech 184 than on non-*Bt* Mech 184. However, there was no survival of *C. chloridae* on MRC 7201 - BGII and RCH 2 cotton hybrids due to early mortality of *H. armigera* larvae.

**Effect of *Bt*-transgenic cottons on parasitism of *Helicoverpa armigera* eggs and larvae under farmer's field conditions:** Survey of *Bt*-transgenic and non-transgenic cottons for natural parasitization of eggs and larvae of *H. armigera* at farmer's fields from south-central India (Andhra Pradesh, Maharashtra and Karnataka) during the 2007 cropping season revealed that there were no significant differences in parasitism of *H. armigera* eggs between *Bt*-transgenic and non-transgenic cottons across regions. Also, there were no significant differences in larval and larval-pupal parasitism. *Trichogramma* spp. was the major egg parasitoid, while *C. chloridae* was the predominant larval parasitoid, and *Sturmiopsis* sp. as larval-pupal parasitoid. The results suggested that *Bt*-transgenic cottons have no major adverse effects on the activity of natural enemies of *H. armigera* under field conditions.

HC Sharma and MK Dhillon

#### **Activity 6C.5.4: Develop mechanisms to cope with pest outbreaks and develop pest management modules**

*Milestone: Chickpea pod borer, groundnut leaf miner, red hairy caterpillar and Spodoptera prediction model validated (GVRR) 2009*

After the initial collaboration with Indian Institute of Information Technology (IIIT), Hyderabad, India for developing pest forecasting models, collaboration with Dhirubhai Ambani Institute of Technology, Gujarat, India was developed to strengthen this activity. They have confirmed the appointment of a software specialist to take up this approach further. With the available information on red hairy caterpillar we envisage the effective prediction model for this pest in the near future.

GV Ranga Rao

*Milestone: Tools for pest identification and nature of damage for different crops developed (HCS/GVRR) 2008*

**Development of insect pest diagnostic and management tools:** The e-learning systems developed in collaboration with Knowledge Management and Sharing Unit on groundnut and chickpea pest diagnosis and management have been shared with NARS through the VASAT website. This would be an effective extension tool for NARS extension staff, scientists and farmers. The information available on insect pests and diseases of ICRISAT mandate crops has been collated on CDs for effective utilization by the end users.

GV Ranga Rao

*Milestone: Tools for detection and quantification of NPV samples developed (GVRR/FW) 2008*

**Development of efficient diagnostic tool to detect the quality of virus products:** The ELISA protocol for the diagnosis and quality control of NPVs of *Helicoverpa armigera*, *Spodoptera litura* and *Amsacta albistriga*, developed at ICRISAT has been standardized by running several samples of predetermined doses and the reliability has been established. Utilizing this technology, field samples collected during rainy 2007 season on pigeonpea crop revealed 37, 71 and 80% NPV infection at 4<sup>th</sup>, 7<sup>th</sup>, and 8<sup>th</sup> day after NPV application in the field, respectively. There was no field infection of NPV in the samples collected 3 days after spray, which indicates the latent period of the virus after larval infection. The larval samples after 10<sup>th</sup> day of application showed a decline in rate of infection (50%) indicating declining persistence of NPV. These kits are handy and can be an effective tool for quick detection and quantification of NPVs of the above three pest species.

GV Ranga Rao

*Milestone: Screening groundnut germplasm and breeding material for resistance to foliar pests organized (GVRR/SNN/HDU/RA) 2009*

During postrainy 2006-07, germplasm trials at the crop maturity phase were evaluated for incidence of defoliators (range 1 - 25%) and Bud Necrosis Disease (BND) (range 0 - 30%). The observations across 2,706 lines resulted in the selection of 62 accessions with negligible incidence (up to 1% defoliation, and 0% BND incidence) compared to controls such as M 13, Gangapuri, ICGS 44 and ICGS 76 with 5, 15, 10 and 3% defoliation, and 0, 9, 14 and 9 % BND, respectively.

Groundnut breeding materials in 36 trials consisting of 911 entries (preliminary and advanced trials) were evaluated against defoliators and BND. There was 1 - 8% defoliation and 0 - 42% BND incidence across trials. Under such situation, 82 lines were promising (1% defoliation) against defoliators, 62 against BND (1% infection) and 14 lines for both. Besides resistance to biotic stresses, some of the lines (entry number 1 of EFDRGVT (SB), entry no. 2 of EMGVT (SB), entry no. 22 of PMGVT (SB), entry no.21 of AAFRGVT -2) were good yielders (> 6 t ha<sup>-1</sup>). These promising materials will be further evaluated during 2007-08 postrainy season for confirmation and consistency of their performance.

GV Ranga Rao

*Milestone: Potential kairomones for attracting Helicoverpa adults identified (GVRR/HCS) 2009*

Project proposal in support of Kairomone research to donors have so far not yielded any positive response. However, we are making efforts to find a funding agency to support this activity.

GV Ranga Rao

*Internal output target 6C.6: New technologies evaluated, disseminated and their impact documented*

#### **Activity 6C.6.1: Exchange improved technologies and new knowledge with ARIs, NARS, NGOs, private sector and farmers' groups**

*Milestone: Pest management packages developed and disseminated through mass media, literature and e-learning (GVRR/OPR/HCS/CLLG/SNN/SP) Annually*

1. Diwakar B and Ranga Rao GV. E-learning system for chickpea and groundnut insect pest diagnosis and management strategies updated and shared through VASAT website.
2. Ranga Rao GV. Double Agent. CGIAR News. October 2007.
3. Ranga Rao GV. 2007. Death Leads to Life. Biocontrol News and Information – IPM systems 28 (4) 76N-77N.

GV Ranga Rao

**Capacity building and knowledge exchange:** Six researchers from different countries (China - 1, India - 2, Philippines - 1, Vietnam – 1 and Myanmar - 1) were trained in groundnut breeding and seed production technologies. Queries related to different aspects of groundnut from farmers and students were attended to on various occasions. Seven journal articles, one book, one book chapter, 9 conference papers and two information bulletins were prepared on different occasions and information shared.

**International trials and advanced breeding lines:** We supplied 70 trait-specific sets of international trials (short-duration, medium-duration, drought tolerant, foliar diseases resistant, Aflatoxin tolerant, confectionery) and 156 advanced breeding lines and segregating populations to collaborators in Bangladesh, China, India, Korea, Myanmar, Turkey and Vietnam.

#### **Variety Releases/ Likely Releases by NARS**

Thirteen varieties were released by 5 national programs (India, Philippines, East Timor, South Africa and Vietnam) during 2007.

##### **India**

ICGV 00348 - a drought tolerant variety has been identified by the All India Coordinated Research Program on Groundnut (AICRP-GN) for its release in Zone V, comprising Andhra Pradesh, Karnataka, Tamil Nadu and Kerala states of India during the rainy season.

ICGV 93261 - a drought tolerant variety as “Ajeya”, and ICGV 93260 - a drought tolerant variety as “Vijetha” were proposed for release.

Three chickpea varieties (BGM 547, BGD 128 and Phule G 9425-9) have been released for cultivation in India during 2007.

### **East Timor**

The Ministry of Agriculture, East Timor, after three years of evaluation, has released confectionery groundnut variety ICGV 88438 as “Utamua”.

### **Philippines**

ICGV 00440 - a Virginia Bunch groundnut variety and another variety NSIC Pn 11 were released in the Philippines.

### **South Africa**

Recently, ICGV 98369 - a foliar diseases resistant variety was proposed for release as “Inkanyezi” in South Africa.

### **Vietnam**

The groundnut varieties (L18 and L 23) were released in Vietnam.

Literature on “Improved Cultivation Practices for Groundnut” was developed in English and Telugu. This literature would be distributed to farmers and field workers.

SN Nigam and R Aruna

### **Activity 6C.6.2: Strengthen the NARS and farmers capacity in application of diagnostic tools and integrated aflatoxin management technologies**

*Milestone: Integrated aflatoxin management technologies disseminated through farmer participatory trials and village level training courses (FW/SNN) Annual*

**On-farm trials for Aflatoxin management in Anantapur:** Participatory varietal selection process was organized in 2006 rainy season with 2 varieties (ICGV 94379 and 94434) in 3 villages, and 3 farmers in each village of Anantapur district (Andhra Pradesh, India). Due to severe drought conditions, only 6 farmers in 2 villages planted the trials. Performance of the 2 selected groundnut improved varieties was better in all the 6 farmers fields in two villages in Anantapur, and produced higher pod and haulm yield than the control TMV 2. Highest pod yield 1412 kg ha<sup>-1</sup> was obtained with ICGV 94434 in Gummallakunta village. ICGV 94379 produced upto 32% higher pod yield in 5 of the 6 fields in two villages; similarly ICGV 94434 produced upto 37% higher pod yield in all six fields. Overall, both varieties produced around 11% higher pod yields in both the villages against the control, which yielded 1010 kg ha<sup>-1</sup>. From each plot, about one kg pod sample was drawn, after taking the bulk pods, the remaining were shelled and sorted into large and small kernel sub-samples. Groundnut kernel sub-samples from each plot were used to determine *A. flavus* seed infection using blotter plate method and aflatoxin contamination by indirect competitive ELISA method. Seed infection ranged from 0 - 18% and aflatoxin 0 - 1082 µg kg<sup>-1</sup> in individual sub-samples. The susceptible cultivar TMV 2 showed higher levels of seed infection and aflatoxin contamination in all the fields. Analysis of all grades of kernel sub-samples indicated that improved varieties showed reduction in *A. flavus* infection (38 - 61%) and aflatoxin contamination (57 - 77%) over the control TMV 2 (Figs. 9 and 10). Irrespective of variety, kernels from damaged pods contained high level of aflatoxin (range 0 - 2150 µg kg<sup>-1</sup>), because damaged pods become vulnerable to fungal infection and subsequent aflatoxin production. Considering the complex nature of the aflatoxins problem in groundnut, the overall mean of the two villages for bulk seed, and large and small kernels of improved varieties showed good tolerance to aflatoxin contamination. In addition, these lines produced 11% higher pod and haulm yields than the local control TMV 2.

On-farm participatory varietal evaluation was continued during 2007 rainy season with 4 varieties (ICGV nos. 91278, 94379, 94434 and 91114) in 42 farmers' fields in six villages in Anantapur, and with 5 varieties (ICGV nos. 91341, 93305, 94379, 94434 and 91114) in 20 farmers' fields in 4 villages in Chittoor (Andhra Pradesh, India). The trials in farmers' fields were monitored during the crop growth period and at harvest. The crop was harvested, and pod samples for *A. flavus* infection and aflatoxin content are being processed. During the trial monitoring, the farmers expressed their happiness over the performance of the improved varieties, and most of them are willing to continue with these varieties on their own. The trials yield data indicated that the improved varieties produced higher pod and haulm yields in most of the farmers' fields in both the districts, and data analysis is in progress.

To disseminate aflatoxin management technologies, farmer participatory trails were organized at Mallapuram village in Anantapur (Andhra Pradesh, India) during the 2006 rainy season. The trial was laid out in 10 farmers

fields. Treatments included: i) compost with bacteria @ 5 t ha<sup>-1</sup>, ii) gypsum application 500 kg ha<sup>-1</sup>, iii) *Trichoderma* 2 kg ha<sup>-1</sup>, iv) combination of all the three, and v) control with 100 m<sup>2</sup> plot size. *Trichoderma* and compost were applied before sowing and gypsum was applied at flowering stage. Soon after harvest from each plot, about one kg pod sample was drawn. After taking the bulk pod, and removing damaged pod sub-samples, the remaining pods were shelled and sorted into large and small kernels sub-samples. Analysis of the samples indicated that bulk seed samples had 25 - 50% reduction in *A. flavus* seed infection, and >97% reduction in aflatoxin in the treatments against 108 µg kg<sup>-1</sup> aflatoxin in the control plots. Moreover, 15% higher pod yield was observed with application of compost + gypsum + *Trichoderma* together, followed by 5 - 6% increase in pod yield recorded with two treatments, gypsum and *Trichoderma*. The increase in yield is attributed to good grain filling due to gypsum application while *Trichoderma* helped to maintain good plant population with less mortality due to seedling diseases.

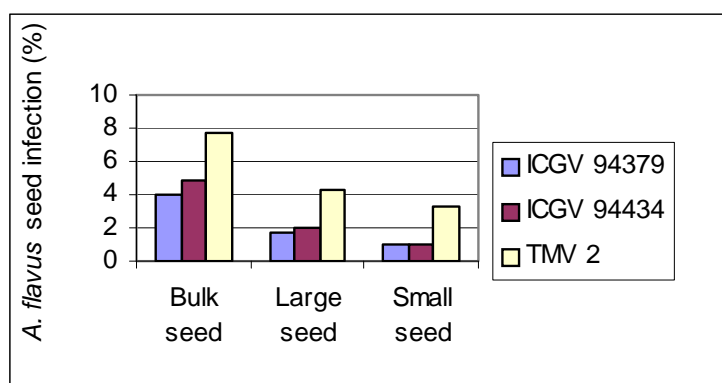


Figure 9. *Aspergillus flavus* infection in improved groundnut lines at Anantapur.

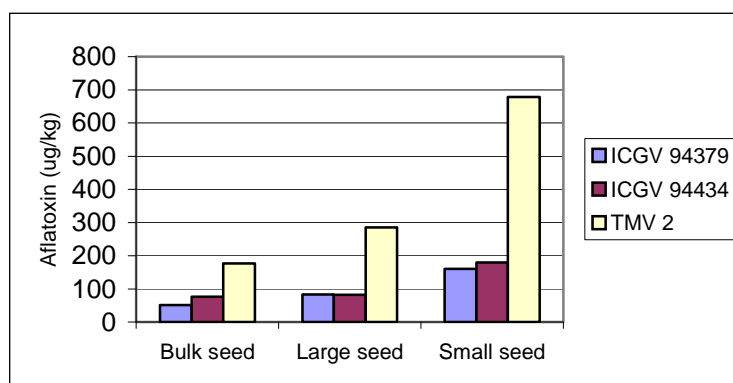


Figure 10. Aflatoxin in improved groundnut lines in Anantapur.

F Waliyar and SN Nigam

*Milestone: Training courses in mycotoxin detection technologies conducted for NARS (FW/PLK) Biannual*

ICRISAT has developed Enzyme Linked Immunosorbent Assay (ELISA) for detection of aflatoxins in groundnut. Aflatoxin detection technology is simple, cost effective and easily adoptable in developing countries. To disseminate aflatoxin detection technologies, we organized an “International Training Course on Detection and Management of Aflatoxins in Crops”, 12-17 November 2007 at ICRISAT, Patancheru, India. About 14 participants from 4 Asian and 3 East and Southern African countries (China 1, India 6, Kenya 2, Malawi 1, Myanmar 1 and Philippines 3) participated. In this course, 50% of the participants were women. During the training course ‘Indirect competitive ELISA, and Direct competitive ELISA techniques were demonstrated to the participants. The course covered theory sessions on management of aflatoxin contamination, and its affect on crops, human and animal health. Further, it looked at agronomic and biological control of aflatoxin, and breeding for resistance to aflatoxins. Moreover, lectures on antibody production and principles of direct and



indirect competitive ELISAs were covered. An opportunity for hands-on experience was given to the trainees, which give them confidence and practical exposure. Finally, the participants were actively involved in interactive discussions with each other, as well as the resource persons.

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## **Project 7: Reducing Rural Poverty through Agricultural Diversification and Emerging Opportunities for High-Value Commodities and Products**

### **System Priority 3: Reducing Rural Poverty through Agricultural Diversification and Emerging Opportunities for High-Value Commodities and Products**

#### **7.1. African Market Garden technology strategy and knowledge database, developed, tested and promulgated with associated capacity development regionally in the SAT of the Sahel in collaboration with AVRDC and ICRAF and assessed in comparison with existing and new potential dryland alternatives**

*MTP Output target: 2007 7.1.1 African Market Garden: 1<sup>st</sup> proof of concept tested and validated in Sahelian countries and report drafted*

##### **Activity 7.1.1: The African Market Garden (AMG)**

The AMG is a low-pressure drip irrigation system for small horticulture producers. It incorporates all the advantages of the pressurized systems with a fraction of its costs. The USAID funded project for dissemination of the AMG in Burkina Faso and Ghana ended in November 2007. About 400 AMG units were installed in both countries. In north Ghana we developed a "Cluster System" where a large number of 500m<sup>2</sup> AMG units are clustered downstream from water dams. This is a very economic system since there is no need for borehole drilling, reservoirs and water pumps. The cluster system was also introduced to Senegal where water supply comes from elevated water towers. In Benin a new version of the AMG was developed. We call it the "Communal System". In this system water is supplied to the field from 20m<sup>3</sup> cement ring reservoirs feeding half-hectare fields. Women groups cultivate the fields. Each woman has a 120m<sup>2</sup> plot. Solar powered pumps supply water. The US NGO called SELF-finances the project. An in depth study of the economics of the "Commercial" and the "Cluster" systems has been conducted and will soon be published in the "Encyclopedia of Water Science". A comparative study of various low-pressure systems from a range of producers will soon be initiated. So far ICRAF assisted in the installation of 2,000 AMG units in 12 Sahelian countries. The AMG activity currently concentrates in Senegal and in Benin. A proposal for the installation of 4,000 AMG units in clusters has been submitted to UNDP-Ghana. The AMG concept has been materially demonstrated to be workable and profitable.

##### **Activity 7.1.2: Heat Tolerant quality vegetables**

In 2007 a vegetable breeder from AVRDC joined the crops diversification team in WCA and a long term breeding of vegetables for the Sudano Sahel was initiated. Seeds of the following heat tolerant vegetable varieties were multiplied: Tomatoes-Icixina, Lettuce-Maya and Queensland, Cucumbers: *Beit Alpha*, Hot pepper-Safi and *Habanero*, Okra-Konni and *Terra*, Moringa-PKM-1 and *Malali* watermelon. Icixina tomatoes dominated the Niamey markets during the rainy season of 2007. Crops and objectives identified for short and medium term research and promotion are: tomato with better shelf life for the main (dry) season and improvement in the existing rainy season Icixina, uniform onion populations with better storage life using two selected populations and F<sub>1</sub>s, purification of the Safi population of hot pepper and identify/develop more adapted populations, selection of heat tolerant sweet pepper sergeants, purification of the *Konni* and *Terra* populations of okra and the breeding of new market types.

##### **Activity 7.1.3: Germplasm acquisition**

A total of 250 specific selected lines of vegetable crops have been introduced from different sources for their use in breeding programs (Table 1). Special efforts were made to collect okra germplasm, wherein a total of 76 accessions of common okra *Abelmoschus esculentus* (104) and others like *A. ficulneus* (3) *A. manihot* (24), *A. manihot var. tetraphyllus* (3), *A. moschatus* (8), *A. tuberculatus* (2) were introduced.

**Table 1. Details on progress of breeding program of different vegetable crops**

| Crops/Collections                   | Source                   | Remarks                                                         |
|-------------------------------------|--------------------------|-----------------------------------------------------------------|
| <b>Tomato</b>                       |                          |                                                                 |
| 14 inbred and 14 F <sub>1</sub> s   | AVRDC, HQ                | With heat tolerant pedigree and parents                         |
| 2 varieties (Tanya and Tangeru)     | AVRDC-RCA                | Popular in East Africa                                          |
| <b>Hot peppers</b>                  |                          |                                                                 |
| 10 including three F <sub>2</sub> s | NMSU, US                 | New Mexican fruit for selection                                 |
| 32 lines including CMS pairs        | AVRDC, HQ                | Germination of 10 Mexican and six habanero lines were very poor |
| <b>Sweet pepper</b>                 |                          |                                                                 |
| 3 F <sub>2</sub> s                  |                          |                                                                 |
| <b>Okra</b>                         |                          |                                                                 |
| 75 accessions                       | NPGS, US                 | Populations collected from India and WCA                        |
| 68 accessions                       | AVRDC, HQ                | Populations collected from Asian countries                      |
| <b>Carrot</b>                       |                          |                                                                 |
| 11 accessions                       | Wisconsin University, US | Heat tolerant genotypes including 2 pairs of CMS lines          |
| <b>Onion</b>                        |                          |                                                                 |
| 3 accessions                        | AVRDC, HQ                | Short day onion populations with better yield                   |
| <b>Indigenous vegetables</b>        |                          |                                                                 |
| 21 accessions                       | AVRDC, RCA               | 11 of jute mallow and 10 of African eggplant                    |

**Activity 7.1.4: Fruit trees**

Introduction and selection of new fruit tree varieties continued in 2007. The *ex situ* collection of fruit tree varieties at Sadore include now about 140 entries. An experiment with five quality grape varieties grafted on the tolerant “Tropical” rootstock has been planted. Five new varieties of Pomme du Sahel were introduced from India bringing our varietal collection to ten varieties; scions of five sweet tamarind varieties were introduced and grafted on to local rootstock. Trials leading to selection of *Ziziphus* rootstocks were initiated. Four *Ziziphus* species namely *Z. mauritiana*, *Z. spina-christi*, *Z. mucronata*, *Z. rotundifolia* are being compared under irrigation and dryland conditions in a sandy soil as well as in degraded lateritic soils. Selection of fig varieties for drying is continuing.

*Domestication of Saba senegalensis*

*Saba senegalensis* is a local fruit plant with great potential for income generation for rural farmers especially women. It shows huge variability in fruit size and quality and has good adaptation to the semi-arid conditions. This justifies ICRISAT’s activities in its domestication. In 2007 important results were obtained on its’ phenology, seed germination and seedling development. A provenance trial will be established in early 2008 at Sadore, under irrigated conditions

**Activity 7.1.5: Domestication of *Acacia senegal***

Work on domestication of *Acacia senegal* in WCA in 2007 focused on identifying key factors determining gum production. Important factors that appear from the preliminary results are:

- The genetic quality of the material, *Acacia senegal* of Sudan-Cordofan origin showed better gum yield when compared to local *A. senegal* trees.
- The number of wounds made on the tree during tapping seems to strongly affect the gum production.
- The age of the plantation
- Ethephon injection in the stems of the trees, proved to be effective in increasing gum production.

### **Activity 7.1.6: Selection of high yielding high quality forage millet varieties**

Long-duration pearl millet varieties produce a high biomass yield prior to flowering. During the 2007 rainy season five long-duration pearl millet varieties were tested for their suitability for forage production. Two planting densities were compared; 1.0x1.0m and 0.5x1.0m. Millet was harvested at the elongation, flowering and wax stages.

The 2007 rainy season had long dry spells and rainfall was below average. Nevertheless the *Malgourou* variety when harvested at flowering gave a dry matter yield of 8.5 t/ha, which was significantly higher than the dry matter yield of the other varieties tested. Forage quality of all varieties at the different cutting stages was analyzed. This trial ends a three years program for selection of forage millet varieties for the Sahel. Results are being prepared for publication.

### **Activity 7.1.7: Selection of high yielding dual- purpose cowpea varieties**

In 2007 we repeated a comparative trial between eight dual-purpose (grains and forage) cowpea varieties. In the 2005 rainy season the variety IT98K-131-2 gave the highest grain yield (1,570kg/ha) and a high forage yield (2,280kg/ha). In the 2007 rainy season (that was drier than in 2005) the best variety was ISV128 that gave a grain yield of 990kg/ha and a forage yield of 1,115kg/ha. In 2007 unsprayed ISV 121 also gave the highest grain yield. Forage quality of the eight varieties is being analyzed. The results of the two years of study are being prepared for publication.

### **Activity 7.1.7: High value trees and traditional vegetables for reclamation of degraded lands**

To reverse eroded desert margins and to halt the process of desertification and mitigate poverty, high value tree crops and under-utilized traditional leafy vegetables have been selected and tested in the degraded lateritic soils of the Sahel. The possible cultivation of perennials and annuals in degraded land will help diversify the existing agricultural system. The economic advantages that would be obtained from these perennial plants growing on degraded land combined with the reclamation of such degraded land through a participatory approach will ensure, more than any other way, the sustainability of this system.

*The perennial species are:*

Pomme du Sahel. The domesticated *Ziziphus mauritiana* from India gives an abundance high quality fruit, firewood and forage

Sweet Tamarind. The domesticated *Tamarindus indica* from Thailand that gives a very high yield of tasty fruit after 4-5 years from planting

High gum producing varieties of *Acacia senegal*. These varieties were recently selected by ICRISAT. They produce 4-5 times more gum than the local wild populations. All the tree species are grafted on hardy rootstocks.

*Acacia tumida*. These are fast growing Australian *Acacias* that provide a range of services (fix atmospheric nitrogen, produce high protein seeds that serve as chicken feed, mulch and firewood). The Australian acacias are pollarded each year before the rainy season.

Henna (*Lawsonia innermis*). A hardy and tall variety introduced from India that provides a valuable dye.

*Boscia senegalensis*. The seeds of this hardy shrub are used during famine. It is famine-alleviating species that is intended to reclaim degraded land.

*The annual plants are:*

The most important annuals planted in the BDL are those of under-utilized traditional leafy vegetables. A total of five annuals are planted 1m x 1m density per split plot within each whole block

- *Senna obtusifolia*, *Gynandropsis gynandra* and *Hibiscus sabdariffa*.

- Two medicinal plants are currently planned: *Cassia acutifolia* (senna)-a very common and popular laxative and *Cassia occidentalis*-an effective anti malaria drug.
- *Crotolaria pallida* a hardy fast growing leguminous plant. Currently the only annual forage being tested.

D Pasternak and team

**Output 7.2: New approaches and technological options to create a strategy to diversify SAT systems using available water resources efficiently to grow high-value commodities that increase incomes for disadvantaged households identified and promoted by consortium partners to Government agencies, donors, NGOs, and CBOs in four countries in Asia by 2008.**

*MTP Output Target: 2007 7.2.1 Exemplar watershed studies completed in four Asian countries and reports published*

**Total number of publications: 13**

**Activity 7.2.1.1: On-site and off-site impact of watershed development: A case study of Rajasamadhiyala, Gujarat, India**

A comprehensive assessment was carried out to document systematically on-site and off-site impact of rainwater harvesting measures implemented at Rajasamadhiyala watershed in Rajkot district of Gujarat since 1978. The report highlights the impact of watershed development on crop production, crop and fodder productivity, improved livelihoods, minimizing land degradation and groundwater availability in the micro-watershed and analyses off-site impact on the downstream villages in terms of groundwater availability and crop production, because of rainwater harvesting in the upstream micro-watershed toposequence. The report provides evidence of constraints/limitations in the watershed for harnessing the full potential of rainfed systems in terms of water productivity.

The case study showed a very large investment of 16.25 million rupees in rainwater harvesting structures in Rajasamadhiyala watershed, which are nine times more than the normal watershed investments made currently by farmers in the watershed. The study revealed that agricultural crop productivity in the watershed area has increased by 119% in the case of groundnut, 53% in cotton, 95% in wheat and by 50% in the case of cumin. It is calculated that the internal rate of return is 9.4% with the cost benefit ratio being 1: 1.24 on the total investment in the watershed. However, overexploitation of groundwater with a doubling of the number of bore wells as well as increased pumping hours in Rajasamadhiyala will jeopardize the development unless suitable legal or social mechanisms for sustainable use of groundwater are put in place by the community.

TK Sreedevi, SP Wani, R Sudi , MS Patel,  
T Jayesh, SN Singh and Tushar Shah

**Activity 7.2.1.2: Socioeconomic profiles, production and resource use patterns in selected semi arid Indian watershed villages**

The report analyzes the socio-economic conditions and resource endowment patterns of the farmers in selected watersheds in Mahabubnagar, Nalgonda and Kurnool districts, Andhra Pradesh, India. The report provides a snapshot of the structure of production in the villages, constraints and potential for increased productivity, social and political networks, and the distribution of assets across social groups. The net household income from diverse sources and their contribution towards total household income are presented. The report also analyses the income inequalities in the watershed villages using inequality decomposition techniques. Livestock income was an inequality increasing source in some watersheds and similarly it acts as an inequality decreasing source in a few watersheds. The effect was more pronounced in the Kacharam watershed as income from the livestock was as an important contributor to the total household income. However, non-farm income also accounts for a significant share of overall inequality in the watersheds. The case study highlights that when land and livestock resources are unequally distributed, land and livestock based watershed interventions may not necessarily generate equitable benefits to all households. Similarly, inequality in land distribution may result in inequalities in distribution of technology benefits from crop production. The paper provides support for watershed interventions through analyzing the sources and patterns of income in the village, for example when crop income is an inequality increasing source and non-farm income has an inequality decreasing effect in the watershed, farmers with large holdings will benefit from crop production technologies rather than the small and landless farmers. Under such situations crop technology interventions should be backed by non income generating activities to create livelihood opportunities for small-scale and landless people.

### **Activity 7.2.1.3: Impact analysis of watershed interventions in Shekta watershed, Maharashtra, India**

A comprehensive assessment was carried out at Shekta watershed in the Ahmednagar district of Maharashtra to study the impact of watershed interventions. The Shekta watershed falls in the semi-arid zone of the rain shadow region of Sahyadris and receives about 465 mm of average annual rainfall. The texture of the soil is clay to sandy clay with pH ranging from 7.5 to 8.2 and with low organic carbon. The report analyzes performance indicators like ground water availability, crop productivity, changes in cropping pattern, crop diversification and fodder availability in the watershed. Significant levels of groundwater availability were reported in Shekta watershed, where watershed interventions improved the ground water availability depth during summer from 0.32 to 1.72 m, while it was 3.68 during the post rainy season from 3.28 m. Similarly, crop diversification was observed in the watershed, where a shift was observed from traditional crops like sorghum and pearl millet to high value crops like cotton, onion and potato. A positive impact in livestock productivity is also presented. A decrease in the population of small ruminants was noted when communities decided to improve the services of common property resources in the village.

TK Sreedevi, SP Wani, Harsha Vardhan Deshmukh,  
Marcella D' Souza, R Sudi and SN Singh

### **Activity 7.2.1.4: Institutional Innovations in Watershed Management in India**

The report highlighted ICRISAT's successful experiences of adapting the Consortium Approach for operationalizing a farmer-centered Watershed Development Program. The study analyzes the special features of the consortium approach, which included the bringing together of diverse partner organizations. Community Based Organisations (CBOs) were benefited by knowledge inputs provided during the program; a more equitable distribution of benefits was ensured; enhanced community participation was observed; natural resources were better sustained and improvements were made more upscalable. The study also examines the relevance of the approach in the changing context of watershed management in India, which has moved from simple soil conservation efforts and productivity enhancement with a compartmental, top-down approach to livelihood improvement, to a more participatory mode with Government investments in building Public – Private Partnerships (PPP). The report gives a snapshot on how communities and natural resources are interlinked and how upward linkages of community organizations can best be exploited for managing natural resources in a rural setting.

TK Sreedevi, TS Vamsidhar Reddy and SP Wani

### **Activity 7.2.1.5: Institutions and Impacts in the ADB – ICRISAT watershed program in China**

The study was undertaken to document the institutional arrangements and associated impacts in the watershed locations in China with special emphasis on collective action and gender equity in the watershed projects, and contribution of the project activities to households and the community. The study highlights the organizational linkages in the project, where the strong two-way relationship between the researcher (representative of the project implementing agency) and the village representative group in Luchebe and Xiao Xin Cun watersheds was of fundamental importance in generating successful interventions. The study analyzes the opportunity for upscaling the learning from the watershed project experience and revealed the importance of linking the relevant departments such as extension agencies in order to take this new knowledge to a wider audience. The study appreciates the strong existence of social organization and cooperatives in the Luchebe watershed and highlights strong cohesiveness found amongst the members, which helped to bring about the success of the project in the watershed. It also highlights fast adoption of technologies in the Luchebe watershed and the rapid rate of system diversification in the watershed as available resources were exploited most effectively. Two farmers cooperative associations with a focus on livestock development in their respective hamlets and one farmers cooperative association with a focus on vegetable growing, were formed during the project period. These groups were found to be very active during the study. The facilitation activities of the cooperative associations helped bring about significant impact on the livelihoods of the watershed community.

Impact of watershed interventions on women revealed that in the Luchebe watershed, increased water availability and increased grass production by using a women's group revolving fund mechanism, expanded pig rearing considerably. An increased number of pigs not only increased incomes but also each house then had a biogas plant using pig and human excreta. Along with increased incomes (1200 CNY per family per year),

drudgery for women (fetching water and wood) was reduced. Increased confidence and ability to face challenges was also evident amongst the women during face to face interviews.

TK Sreedevi, SP Wani, TS Vamsidhar Reddy and R Sudi

#### **Activity 7.2.1.6: Harnessing Gender Power and Collective Action through Integrated Watershed Management for Minimizing Land Degradation and Sustainable Development**

The paper highlights efforts to achieve higher functional literacy for women and enhanced awareness of women's rights through deliberate efforts towards sustainable development of watersheds by harnessing women's strengths equitably. It also presents the importance of the involvement of the younger generation of girls in building up social capital. The educational and nutritional needs of girls should consciously be addressed to promote a more equitable society. Considering the basic rule of collective action that under stress people cooperate better, and that greed for higher personal benefits affects the collective action, there is need to harness gender power through equitable behavior in the watersheds at all levels starting from the family to the watershed.

The most important learning from these case studies is that targeted activities for women as well as other vulnerable groups are very much needed as component activities in watershed programs. The paper emphasizes the necessity of functional literacy through empowerment and training for women to lead their groups well and also the need for social capital development to enhance developmental sustainability of project impact. The study identified that enhanced incomes for the women resulted in more decision making power as well as reducing overall workload and drudgery indirectly. Income-generating activities in the watershed programs and continued interactions amongst the Self Help Group members not only brought sustainability to the institutions but also benefited members through their own experiences and learning from other SHGs. It concludes that increased investment in watersheds to undertake income-generating activities targeted specifically at women and vulnerable groups enhances beneficial collective action and the impact of watershed improvement projects.

TK Sreedevi, SP Wani and P Pathak

#### **Activity 7.2.1.7: Improved livelihood system of farm households through community watersheds: Learnings and insights from Thailand and Vietnam**

The primary objective of the study was to document the major changes that took place in the farming system and their effects on social processes due to watershed project interventions in Thailand and Vietnam. The report highlights the positive changes in farmer production systems, which included changes in cropping systems such as the addition of new crops (legumes and fruit trees), new varieties, adjustment in the cropping calendar and new investments in aquaculture and poultry. It also indicates the contribution of all these interventions to the improvement of income levels, enhancement of community participation, and livelihood fulfillment among household members. The paper indicates that training and exposure to new knowledge provided to farm households opened windows for self-help group formation and new alliances and partnerships. The study identified the inculcation of a sense of ownership among farmers as a major contributing factor to the success of the watershed project in the target areas. The paper highlights, in the social sphere, that an understanding of problems and the ways in which affected farm households respond to them need to be used as enabling mechanisms for watershed improvement initiatives. Specifically, this is required in developing an appropriate framework for evaluating, informing, and educating farm households. It is concluded that the community watershed approach made significant headway in integrating environmental protection strategies with productivity enhancement of farm resources and as such was demonstrably successful in bringing about sustainable development.

P Rosana Mula, SP Wani, Thawilkal Wangkahart,  
NV Thang and Y Supama

#### **Activity 7.2.1.8: Simple and effective IPM techniques for vegetables in Northeast Thailand**

Crop and monetary losses due to pests have been substantial with regard to high value crops, vegetables and fruits in Thailand. Hence, pesticides become the major contributor to production costs (40-60%). The Thai government has planned to reduce pesticide use by 30% with more stringent regulations on permitted pesticide residue content in fruits and vegetables. The paper highlights the performance of an Integrated Pest Management (IPM) System with traps comprising white plastic bottles of 700 ml capacity with openings on both sides and filled with molasses placed at about 30 cm from the ground surface on a bamboo stick. The paper

shows that such traps relatively more effective in attracting insects than the traps placed at 100 and 150 cm above the ground surface. The paper highlighted the performance in terms of net return, where the IPM technique increased net profit by 51 % in cabbage compared to conventional chemical based insect management. The paper reveals that use of IPM is adopted quickly due its ease of implementation using locally available materials

Somchai Chuachin, Thawilkal Wangkahart and Prabhakar Pathak

**Output 7.2. New approaches and technological options to create a strategy to diversify SAT systems using available water resources efficiently to grow high-value commodities that increase incomes for disadvantaged households identified and promoted with associated capacity building by consortium partners to Government agencies, donors, NGOs, and CBOs.**

*Output target 2010*

*7.2.1 Potential proof of concept for use of environment-friendly alternative sources of energy using biodiesel and ethanol from sweet sorghum to use as energy source*

**Activity 7.2.1.1: Research and Development involving evaluation and management trials on *Jatropha* and *Pongamia* plantations**

**Evaluation and documentation of *Jatropha* and *Pongamia* accessions**

*Pongamia pinnata* is a leguminous tree adapted to the problem-soils of the wetter wastelands; and *Jatropha curcas* is a more drought-tolerant shrub, adapted to well-drained wastelands, that is widely grown as a boundary plant in many Asian and African countries. Both produce fruits, containing about 35% inedible oil suitable for use in bio-diesel. Few systematic efforts have been made to evaluate and document the existing variability in seed sources of both these species. In a preliminary study conducted at ICRISAT-Patancheru samples, collected from the various states of India indicated a great variability in terms of oil content and test weight of both *Jatropha* and *Pongamia*. Oil content in the accessions of *Jatropha* varied from 27.4 to 40.6%, whereas oil content in *Pongamia* accessions varied from 21.3 to 40.9%. Similarly, the test weight (100 seeds) of *Jatropha* accessions varied from 44 to 72.6 g and it ranged from 101.2 to 233.2 g among the *Pongamia* collections. This great variability shows the potential of the species for genetic improvement, hence some promising lines in terms of oil content were evaluated under field conditions.

An evaluation study conducted at ICRISAT on the field performance of *Jatropha* accessions revealed that IJC3 recorded the largest plant height (148 cm), stem girth at 10 cm (25.7 cm) and number of branches (6.7) followed by IJC 9 thirty months after planting under rainfed conditions. Flower initiation was observed in IJC3, IJC5, IJC7, IJC8 and IJC9. Similarly, the performance of *Pongamia* accessions showed that maximum growth parameters like plant height (270 cm) and stem girth (20 cm) were recorded in IPC9 followed by IPC10 at 30 months after planting under rainfed conditions.

**Activity 7.2.1.2: Standardization of agronomic practices in *Jatropha* plantations**

Systematic and scientific studies on genetics and agronomic management are not available for either *Jatropha* or *Pongamia* species. ICRISAT has initiated such systematic studies to seek understanding of the potential performance of both *Jatropha* and *Pongamia* under dryland conditions. *Jatropha* and *Pongamia* are generally propagated through nursery grown seedlings. Studies carried out at ICRISAT showed that inoculation of *Jatropha* seeds with Arbuscular Mycorrhizal (AM) cultures at one gram per seed, while dibbling the seed in the nursery bag enhanced seedling height by 34% and stems girth by 10% (Table 1). Similarly, seed treatment with AM and rhizobial cultures resulted in 92 and 46% higher shoot and root mass respectively in *Pongamia* seedlings compared to the control three months after sowing in the nursery (Table 2).

**Table 1. Effect of mycorrhizal inoculation on growth of *Jatropha* seedlings in nursery**

| Treatment              | Plant height (cm) | Stem girth (cm) | Number of leaves |
|------------------------|-------------------|-----------------|------------------|
| Inoculated             | 47                | 6.5             | 16               |
| Non-inoculated control | 35                | 5.9             | 12               |

**Table 2. Effect of *Rhizobium* and mycorrhizal inoculation on nodulation and biomass of *Pongamia* seedlings in nursery**

| Treatment                      | Nodules per seedling | Fresh weight (g/seedling) |      | Dry weight (g/seedling) |      |
|--------------------------------|----------------------|---------------------------|------|-------------------------|------|
|                                |                      | Shoot                     | Root | Shoot                   | Root |
| No treatment (Control)         | 11                   | 5.5                       | 5.0  | 1.2                     | 1.3  |
| <i>Rhizobium</i> alone         | 19                   | 6.0                       | 5.4  | 1.3                     | 1.8  |
| Mycorrhizae alone              | 12                   | 5.8                       | 5.9  | 1.3                     | 1.5  |
| Mycorrhizae + <i>Rhizobium</i> | 17                   | 6.2                       | 7.9  | 2.3                     | 1.9  |
| Mean                           | 15                   | 5.9                       | 6.0  | 1.5                     | 1.6  |
| LSD ( $P \leq 0.05$ )          | 1.8                  | 2.4                       | 2.0  | 0.98                    | 0.69 |

On-station trials revealed that the planting of *Jatropha* at 3x3 m spacing recorded better growth characteristics compared to 4x2 and 3x2 m spacing on Vertisols under rainfed conditions. Studies clearly demonstrate that terminal pruning at 45-60 cm in the first year of planting during the dormant period (*Jatropha* normally sheds its leaves after the cessation of monsoon rains and puts forth new flushes towards the onset of the next monsoon) increased the number of flowering branches and similarly continuous light pruning of secondary and tertiary branches during the dormant period is necessary to ensure improvement in the number of flowering branches and maintaining a suitable canopy spread at a height to facilitate manual picking of seeds.

Of the graded levels of nutrient applied to *Jatropha*, application of 100 g urea + 38 g SSP per plant showed good performance followed by the application of 50 g urea + 76 g SSP per plant. It revealed that there is significant improvement in terms of the number of inflorescences with the application of 100 g of urea per plant per year compared to plants that received 50 g of urea. However there was no other marked difference in growth parameters among the nitrogen treatments. Studies on the evaluation of suitable intercrops with *Jatropha* revealed that intercropping of pearl millet (ICMV 221) gave a grain yield of 1200 kg ha<sup>-1</sup> followed by pigeonpea (ICPV 88094) with 560 kg ha<sup>-1</sup> in two year old plantations with a plant spacing of 3 x 2m

#### **Activity 7.2.1.3. Soil moisture extraction by *Jatropha* plantation in SAT conditions in South India**

*Jatropha* seedlings were planted at a spacing of 2 x 3 m in the BL3 watershed area of ICRISAT in November 2004. Soil moisture was measured up to 30 cm depth using a gravimetric method and beginning from 45 cm up to 225 cm at 15 cm interval with a neutron probe (Troxler model 4302) at 12 locations in the plot. Access tubes for the neutron probe were placed in the interspaces in such a way that the soil volume sampled by the instrument was most directly influenced by the *Jatropha* plants.

Neutron probe measurements were taken initially in October 2005 and are continuing. In the present study, soil moisture measurements up to 100 cm depth only were considered and took into account the rooting depth of the young *Jatropha* plants. Weather was monitored at the Agro-meteorological Observatory at ICRISAT campus. Daily potential evapotranspiration (PET) was computed following the FAO Penman-Monteith method (1998). Monthly evapotranspiration (ET) values of the *Jatropha* plot were estimated (Fig. 1) using the following water balance equation and adjusting suitably for the runoff and deep drainage,

$$ET = P + I + RO + DD + \Delta S$$

Where P is rainfall, I is irrigation, RO is surface runoff, DD is deep drainage and  $\Delta S$  is change in the soil moisture.



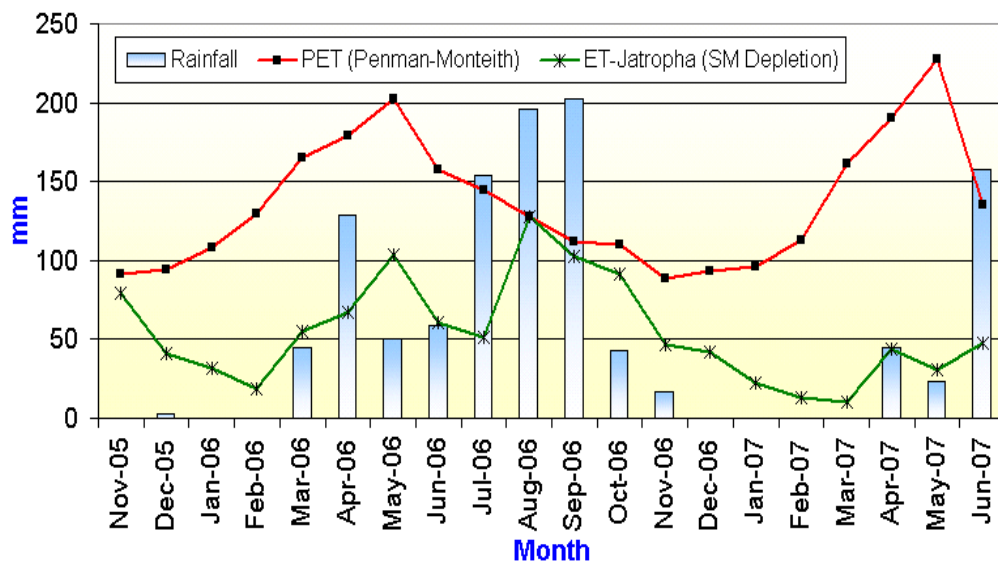


Figure 1. PET and ET measurements in two year old *Jatropha* plantations

Distribution of the volumetric content of soil moisture throughout the soil profile of 225 cm was plotted and shown in Fig. 2. Patterns of soil water depletion indicate that two-year old *Jatropha* plants were able to extract water up to a soil depth of about 100 cm. However, due to their relatively shallow root depth, uptake was mostly from the top 75 cm layer. Water use (evapotranspiration) by *Jatropha* varied from 20-130 mm per month depending on water availability and environmental conditions. This study indicates that contrary to the belief that *Jatropha* consumes less water than other species; under favorable soil moisture conditions, *Jatropha* will use large amounts of water, which promotes luxurious growth.

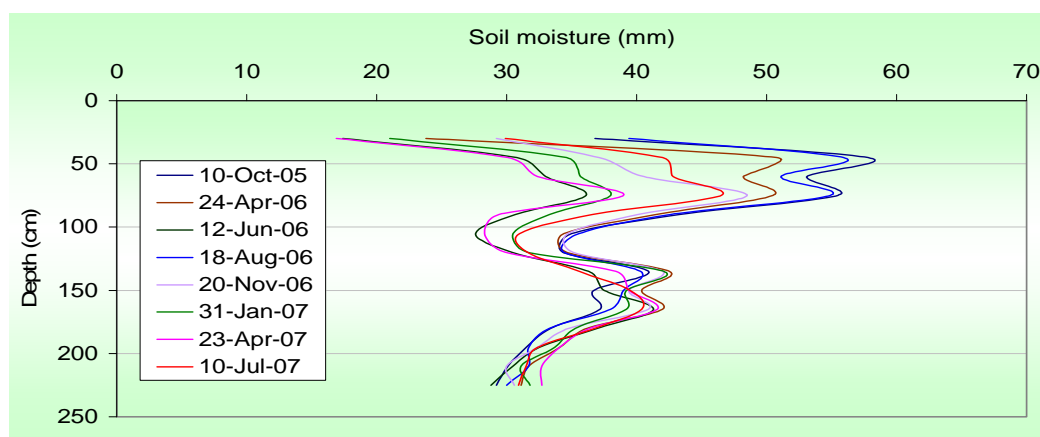


Figure 2. Distribution of volumetric moisture content in root profile of two year old *Jatropha* plantations

#### Activity 7.2.1.4: De-oiled cake of *Jatropha* and *Pongamia* as a source of nitrogen for field crops

Oilcake is a by-product after extraction of oil for biodiesel which appears to be a very useful commodity for soil nutrient enhancement as it has good macro and micro-nutrient content. Thus, it has excellent potential as a broadly-based organic fertilizer. Four kilograms of fresh seed of *Pongamia* or *Jatropha* gives about three kilograms of cake. Analysis of the cake of *Pongamia* and *Jatropha* indicated the presence of all the essential elements required for plant growth. It was particularly rich in nitrogen (4-6%) and sulphur (0.24 -0.36). On-farm trials with soybean revealed that the application of *Pongamia* cake @ 12 kg N ha<sup>-1</sup> resulted in 40.9% additional net income compared to current farmer practice. Similarly, application of 70 kg N ha<sup>-1</sup> in maize using *Pongamia* cake resulted in 47.7% additional income compared to farmer practice. In cotton, application of N (128 kg N ha<sup>-1</sup>) with *Pongamia* cake improved additional income by 35.9% compared to the application of same quantity of nitrogen through inorganic fertilizer (Table 3).

**Table 3. Response of soybean, maize and cotton to the application of *Pongamia* cake and inorganic fertilizer in on-farm trials conducted at Adilabad district, AP, India.**

| Crop    | Treatment            | N applied (kg ha <sup>-1</sup> ) | Yield (kg ha <sup>-1</sup> ) | Income (Rs) | Cost of nutrients (Rs) | Additional income over FP (%) |
|---------|----------------------|----------------------------------|------------------------------|-------------|------------------------|-------------------------------|
| Soybean | Farmers Practice     | 16                               | 900                          | 10800       | 450                    | -                             |
|         | Pongamia cake (PC)   | 12                               | 1340                         | 16080       | 1500                   | 40.9                          |
|         | Inorganic fertilizer | 23                               | 1450                         | 17400       | 250                    | 65.7                          |
|         | Fertilizer + PC      | 17                               | 1650                         | 19800       | 1500                   | 76.8                          |
| Maize   | Farmers Practice     | 40                               | 1200                         | 6000        | 1125                   | -                             |
|         | Pongamia cake        | 71                               | 2240                         | 11200       | 4000                   | 47.7                          |
|         | Inorganic fertilizer | 92                               | 2390                         | 11950       | 1000                   | 124.6                         |
|         | Fertilizer + PC      | 81                               | 2560                         | 12800       | 5000                   | 60.0                          |
| Cotton  | Farmers Practice     | 80                               | 894                          | 16986       | 1810                   | -                             |
|         | Pongamia cake        | 128                              | 1793                         | 34067       | 10500                  | 55.3                          |
|         | Inorganic fertilizer | 128                              | 1065                         | 20235       | 2900                   | 14.2                          |
|         | Fertilizer + PC      | 128                              | 1158                         | 22002       | 6700                   | 0.8                           |

**Activity 7.2.1.5: Value addition of deoiled cakes of *Jatropha* and *Pongamia* through vermicomposting**

A pilot scale study was carried to enrich and improve the availability of nutrients in deoiled biodiesel-cake by earthworms. The experiment is also aimed to assess the appropriate time for releasing earthworms into the cake and to decide what filler organic material is most suitable for the vermicomposting of deoiled cake. Organic materials like millet husk or wild grass and cow dung slurry were added at the rate of 60 and 10 % respectively on a weight basis with deoiled cake and left for microbial or natural decomposition in pots (the proportion of organic materials, cow dung slurry and deoiled cake was decided based on the previous experience of similar work in ICRISAT during 2004). Regular watering was carried out to keep the heap of cake at field capacity. After an interval of 35 days of microbial decomposition, 75 earthworms per sample were released to encourage further decomposition. However, the first earthworms released died and hence 150 further earthworms were released into the cake after 50 days of natural decomposition. Composting with earthworms was allowed for another 30 days in the same pot and the matured compost was harvested.

Generally, the most appropriate time for releasing earthworms for vermicomposting is indicated by the appearance of cracks over the heap (which happens 30-35 days after initial decomposition). However, earthworms released 35 days after initial microbial decomposition failed to survive. The temperature of the heap was found to be 28 – 30°C during the release of earthworms.

The temperature of the heap subsided to 25 -27°C after 50-55 days of initial decomposition and was then found to be suitable for releasing earthworms for further composting.

The multiplication rate of earthworms in the heap was quantified at the end of the composting period, which revealed it ranged from 157–218 in the combination of *Jatropha* deoiled cake with grass; 117-223 in *Jatropha* deoiled cake with millet husk; 163-292 in *Pongamia* deoiled cake with grass and 120-196 in *Pongamia* deoiled cake with millet husk.

**Activity 7.2.1 Crop diversification through high-value crops**

The true value of cereal grain crops has fallen for decades. This puts pressure on smallholder farmers having only a small landholding of 1-2 ha to support their livelihoods from grain farming. Hence dryland smallholder farmers are being encouraged to find ways to generate greater crop-value from their investments in inputs and labor. Rapid urbanization across marginal areas, changing food habits, increased awareness about quality diets and entry of the global market giants in retail trading means that the demand for vegetables and fruits are now most promising and hence diversifying cropping systems with such high-value crops can potentially multiply

farm incomes several fold. Dryland farmers can grow such high value crops on small areas using supplemental irrigation where opportunities are presented for conserving runoff during the rainy season.

#### Activity 7.2.1.6: Balanced nutrition for vegetables production in Sujala watersheds, Karnataka, India

Trials on balanced nutrition including micro-nutrients were carried out with summer irrigated vegetables in the Sujala watersheds in S. India during 2007. The results revealed that application of 60 kg urea, 28 kg DAP, gypsum 80 kg, borax 2 kg, and 10 kg ZnSO<sub>4</sub> 0.4ha<sup>-1</sup> increased fruit yields in ridge and bitter gourds, chillies, brinjal and tomatoes compared to farmer practice (Table 4). However, it was found that the magnitude of yield increase is highest in tomato when compared to farmer practice. The trials showed a significant response of vegetables to micronutrient applications as previously observed for field crops.

**Table 4. Response of vegetables to balanced nutrition in Sujala watersheds, Karnataka, India**

| Crop           | Fresh fruit yield (q ha <sup>-1</sup> ) |      | Farm gate price (INR q <sup>-1</sup> ) | No of farmers | Additional cost (INR ha <sup>-1</sup> ) | Additional net returns (INR ha <sup>-1</sup> ) | BC ratio |
|----------------|-----------------------------------------|------|----------------------------------------|---------------|-----------------------------------------|------------------------------------------------|----------|
|                | FP*                                     | IP** |                                        |               |                                         |                                                |          |
| Ridge gourd    | 54                                      | 63   | 600                                    | 2             | 3050                                    | 5700                                           | 1: 1.87  |
| Bitter gourd   | 30                                      | 39   | 925                                    | 2             | 3050                                    | 8250                                           | 1: 2.71  |
| Green chillies | 60                                      | 85   | 550                                    | 4             | 3050                                    | 13000                                          | 1: 4.26  |
| Brinjal        | 60                                      | 80   | 680                                    | 4             | 3050                                    | 12770                                          | 1: 4.19  |
| Tomato         | 112                                     | 171  | 640                                    | 4             | 3050                                    | 34800                                          | 1: 11.4  |

FP\* Farmers' practice, IP\*\* Improved Practice: NP+ SBZn : 150 kg urea, 70 kg DAP, gypsum 200 kg, borax 5kg and 25 kg ZnSO<sub>4</sub> ha<sup>-1</sup>

#### Activity 7.2.1.7: Monitoring pesticide residues in vegetables in Kothapally watershed, Andhra Pradesh, India

Strategic research carried out monitoring pesticide residues in the water bodies and various crops in Kothapally village revealed information that helps to strengthen the eco-friendly concept in the watersheds. Of the 75 samples analyzed (59 vegetables, 16 water samples), only 7 samples were found with residues of chloropyriphos above maximum residue limit (MRL) prescribed by FAO. However, most of the samples had traces of the insecticides which were tested (Endosulfan, Monocrotophos, Chlorpyriphos and Cypermethrin). It was also observed that the increase in residue levels in all crops as the crop stage advances during the post rainy season. Crops in IPM fields had relatively less residue (cucumber 0.0127ppm, tomato 0.0177ppm) than non-IPM crops (cucumber 0.0372ppm and tomato 0.0437ppm). The overall residue of these four chemicals in IPM fields showed about 60% reduction over non-IPM fields.

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AV KesavaRao and Ch Srinivasrao

#### Output 7.4. Opportunities for the market exploitation of biodiesel tree products by the poor promoted with associated capacity building

##### Output target 2010

*7.4.1: Proof of concept that biodiesel trees are an economically and socially viable products for very poor and landless communities when granted usufruct rights on low quality non-titled land*

##### Activity 7.4.1: Strategies for sustainable production of biodiesel crops and bringing small and landless farmers in global biodiesel initiatives

Many developing economies depend on an increasingly unstable world for their modern energy requirements. In this context, greater use of biofuels could help bring the oil market into better balance and possibly reduce oil prices. Fortunately many of the developing nations lie in tropical zones, where relatively low-cost biofuel crops such as sugarcane and oil palm are already grown. However the first concern involves the devotion of lands to biofuel crops, with diversion from other purposes such as food and feed production. To address this overriding concern, using the large degraded, dryland and marginal lands in developing nations suitable for hardy bio-diesel crops makes sense for local communities. While providing an income earning opportunity for

the poor, these perennial tree and shrub crops also help rehabilitate these lands by building the fertility of their soils.

#### **Activity 7. 4.1.1: Participatory approach to rehabilitate Common Property Resources (CPRs) with biodiesel plantations**

Degraded and marginal lands that are unsuitable for food production may be used to grow biofuel crops without disturbing the global food web. Potential sources of biodiesel like *Pongamia pinnata* a N<sub>2</sub>-fixing tree and *Jatropha curcas*, could be suitable candidates for growth in such marginal lands because of their proven adaptability to harsh environments. They are also not grazed by animals and thus it is possible to encourage their growth without protection in rangelands. It is a common scene in south Asia, where CPRs in the villages are degraded and usually form the catchment area in watersheds. The CPRs are unable to render much service to the community in terms of fodder and fuel, which they are intended for due to severe land degradation.

ICRISAT validated a novel approach for rehabilitating degraded common property resources (revenue lands) using biodiesel plantations involving local smallholder and landless communities. CPRs for rehabilitating with biodiesel plantations were identified through a consortium approach involving officials from government departments. Institutional arrangements were made in the locations identified to allow unorganized agricultural labors to be the stakeholders in such a model. The village agricultural labors were encouraged to form self help groups and to work to establish biodiesel plantations on CPR land. It was resolved to distribute equal land area to each self help group for biofuel plantation. The self help groups benefit not only by earning from wages by giving them the harvesting rights (usufruct rights) once the plantations start to yield economic benefits. This institutional arrangement gives the wage earners ownership in the development process and a new source of livelihood for the landless.

Suitable institutional mechanisms were framed to improve the cohesiveness of group members by encouraging them to form microfinance units and to contribute 5 rupees per person towards the group accounts. The savings were made to be a revolving fund and were agreed for use for internal lending among the members at nominal interest rates. The model implemented in a village comprised eight groups (each group consists of 10 members) which could establish *Jatropha* plantations in 140 ha successfully. Each group had a balance of 7550 rupees (USD 190) through savings after one and a half years and the total benefit was approx. \$1510 for all groups put together. The initiative generated employment of 75 person-days per ha in the first two years, out of which off season employment accounted for 42 person-days per ha for the communities. Soil and water conservation measures were also embedded into the project along with initiatives to ensure better establishment of *Jatropha*.

#### **Activity 7.4.1.2: Integrating indigenous fodder grasses with biodiesel plantations in low quality grazing lands**

ICRISAT has evolved a model for restoring grazing lands through integrating biodiesel plantations with fodder grasses. In many parts of semi-arid systems, livestock is the mainstay of livelihoods where common grazing lands are used to support the fodder requirements of the livestock population. Over time, common grazing lands are degraded and grasses grown are neither palatable nor sufficient to feed the livestock population. Village communities can be sensitized for collective action, to contribute labor for the development of the grazing land. Initially, the lands are restored with biodiesel crops for preventing soil erosion and subsequently sowing of grasses was taken up in between rows of plantations with soil and water conservation structures. An institutional mechanism was designed to safeguard the restored areas and harvest the fodder grasses sustainably. The model created a sense of ownership among the community that helped in the protection of natural resources and their effective management.

#### **Activity 7.4.1.3: Supporting farmer activities in the Value-Chain of Biofuels through Public Private Partnerships**

Private companies are mushrooming in biofuel initiatives because of the large demand for Biofuels from favorable and supporting government policies for using biofuels in the transport sector. The Indian government promotes public private partnership (PPP) as part of its policy framework to attract private corporate to invest in biofuel production. The main bottleneck in biofuel cycles is the availability of raw material for biodiesel production. In order to address this constraint, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, has initiated activities in a farmer-based biofuel production system and has established a bio-diesel

refinery within the public private partnerships framework in Andhra Pradesh. GTZ has supported a PPP initiative between ICRISAT and Southern Online Bio Technologies Ltd., (SBT) for supporting farmer activities in the value-chains of biofuels with the objective of assisting smallholder farmers and the rural poor within 50-100 km of the bio-diesel plant site in the planting of oil-bearing trees, oil extraction, and marketing through training, technology support, and field demonstrations. ICRISAT is also looking into new sources of tree-borne seeds for bio-diesel production that can be grown on degraded lands under this PPP initiative. ICRISAT will also devise value-addition mechanisms for smallholder farmers and disseminate results to decision makers in order to better guide their policies in renewable energy and rural development.

#### Activity 7.4.1.4: Growers' model in PPP biodiesel initiative

The model involves small and marginal households having low quality land not suitable for economic arable farming. Smallholder and marginal farmers are encouraged to grow biodiesel crops with technical backstopping from ICRISAT and with a formal buy back agreement from SBT. The agreement draft was prepared to safeguard the farming communities with special clauses concerning the cost of the produce while buying by the factory. The eight villages viz., Mohammadabad, Narayanapur, Kothaguda, Jangam, Vaeilpally, Chillapur, Sarvail and Gujja in Narayanapur mandal were selected for establishing block plantations of *Pongamia* through the PPP initiative covering 25 ha during the rainy season of 2007. The criteria for selection of farmers were willingness, availability of low quality land and assigned lands by the government. It was explained to farmers who enrolled under the grower model about the buyback arrangements with the factory. The seedlings produced by various self help groups under PPP initiative were used for establishing the plantations in the farmer holdings.

#### Activity 7.4.1.5: Collector's Model in Biodiesel initiative

A collectors model encourages landless communities to collect seeds of *Pongamia* and *Jatropha* either from forests or wild plantations. The landless and vulnerable communities are empowered through various activities such as nursery raising, oil expelling, and sale of deoiled cake under micro entrepreneurship. ICRISAT has promoted nursery raising through trained self help groups (SHGs). The collectors (SHGs) form an important component in the value chain by producing *Pongamia* seedlings, which in turn will be used to plant in farmer holdings. The groups realized an immediate benefit by selling the seedlings to the farmers who enrolled under the biodiesel initiative. The details on the number of seedlings grown by each group and employment and income generated in the initiative are given in Table 5.

**Table 5. Benefits generated through *Pongamia* Nursery under biodiesel initiative by various Self-Help Groups (SHGs) in Narayanapur mandal, Nalgonda district, AP, India**

| Name of the SHG   | Hamlet and Village                     | Number of seedlings grown | Income generated (INR.) | Employment generation |
|-------------------|----------------------------------------|---------------------------|-------------------------|-----------------------|
| Janardhana SHG    | Chillapur                              | 1800.                     | 4500.00                 | 15 person days        |
| Lakshmi SHG       | Botimeedi thanda, Vaeilpally village   | 2930                      | 7325.00                 | 25 person days        |
| Venkateshwara SHG | Venkambavi thanda Mohammadabad village | 2300                      | 5750.00                 | 21 person days        |
| Venkateshwara SHG | Narayanapur                            | 2400                      | 6000.00                 | 21 person days        |

SP Wani, TK Sreedevi, S Marimuthu, Ch Srinivasrao, Sathishkumar and Naveenkumar

#### List of Publications in 2007

##### Journal Articles:

**Ratna Reddy V, Shiferaw B, Bantilan MCS, Wani SP and Sreedevi TK.** 2007. Collective Action for Integrated Watershed Management in Semi-Arid India: Strategic Policy and Institutional Options. Global Theme on Institutions, Markets, Policy and Impacts. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502 324, Andhra Pradesh, India. Policy Brief No. 11.

**Rosana Mula P, Srinivasarao Ch, Kesava Rao AVR and Wani SP.** 2007. Drivers of Success for Watershed Management and Livelihoods: Experiences in God's Own Country' of Kerala, India. Journal of SAT Agricultural Research, Vol 5, Issue 1.

#### **E-Journals:**

**CHUC N T, Piara Singh, Srinivas K, Ramakrishna A, CHINH NT, Thang NV, Wani SP and Long TD.** 2006. Yield Gap Analysis of Major Rainfed Crops of Northern Vietnam Using Simulation Modeling. Global Theme on Agroecosystems Report No. 26. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.

**Subrahmanyam S, Bezkorowajnyj Peter, Shiferaw Bekele, Wani SP, Parthasarathy Rao P and Nageswara Rao GD.** 2006. Crop-livestock linkages in watersheds of Andhra Pradesh. Global Theme on Agroecosystems Report No. 29. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

**Kesava Rao AVR, Wani SP, Singh Piara, Irshad Ahmed M and Srinivas K.** 2006. Agroclimatic characterization of APRLP-ICRISAT nucleus watersheds in Nalgonda, Mahabubnagar and Kurnool districts. Global Theme on Agroecosystems Report No. 30. Patancheru 502 324 Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

**Bhatia VS, Singh Piara, Wani SP, Kesava Rao AVR and Srinivas K.** 2006. Yield Gap Analysis of Soybean, Groundnut, Pigeonpea and Chickpea in India Using Simulation Modeling. Global Theme on Agroecosystems Report No: 31. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 156 pp.

#### **Proceeding papers:**

**Sreedevi TK and Wani SP.** 2007. Leveraging Institutions for Enhanced Collective Action in Community Watersheds through Harnessing Gender Power for Sustainable Development. Pages 27-39 *in* Empowering the Poor in the Era of Knowledge Economy (Srinivas Mudrakartha and VIKSAT, Ahmedabad, Gujarat, eds.).

**Wani SP and Sreedevi TK.** 2006. Harnessing Gender Power and Collective Action through Integrated Watershed Management for Sustainable Development and Minimizing Land Degradation. Pages 114-125 *in* Proceedings of Regional Workshop on Deserts and Desertification. Conducted by APARD, Rajendranagar, Hyderabad 29-30 Dec 2006.

**Wani SP and Sreedevi TK.** 2007. Strategy for Rehabilitation of Degraded Lands and Improved Livelihoods through Biodiesel Plantations. Pages 50-64 *in* proceedings of 4th International Biofuels Conference held during 1-2 February 2007 at New Delhi.

**Wani SP, Sreedevi TK, Rockstrom J, Wangkahart T, Ramakrishna YS, Yin Dxin, Kesava Rao AVR and Zhong Li.** 2007. Pages 89-106 *in* Improved livelihoods and food security through unlocking the potential of rainfed agriculture. Food and Water Security (Aswathanarayana U, ed.).

#### **GT-AES Reports:**

**Pathak P, Wani SP, Sudi R, Chourasia AK, Singh SN and Kesava Rao AVR.** 2007. Rural Prosperity through Integrated Watershed Management: A Case Study of Gokulpura-Goverdhanpura in Eastern Rajasthan. Global Theme on Agroecosystems Report no. 36. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 52 pp.

**Ramkumar Bendapudi, Shiferaw Bekele, Wani SP, Nageswara Rao GD and Sreedevi TK.** 2007. Socioeconomic profiles, production and resource use patterns in selected semi-arid Indian watershed villages. Global Theme on Agroecosystems Report No. 34. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 90 pp.

#### **Oral presentations, conference / Abstract papers/meetings:**

**Sreedevi TK, Wani SP and Pathak P.** 2007. Harnessing Gender Power and Collective Action through Integrated Watershed Management for Minimizing Land Degradation and Sustainable Development. Paper submitted to Journal of Financing Agriculture.

**Wani SP and Sreedevi TK, Yin Dixin, Thawilka Wankahart, and Thang, NV.** 2007. Conservation of Natural Resources and their Efficient Use for Sustainable Development in Asia. Paper submitted in National Seminar on Rainfed Agriculture held during 23-24 April 2007 at Jaipur.

**Project 8:  
Poverty alleviation and sustainable management of water, land, livestock and forest  
resources, particularly at the desert margins of the Sahel and the drylands of ESA  
(SSA Desert Margins Program SWEP)**

**Ouput 8.1. Nine benchmark site characterization on the improved understanding of ecosystem dynamics with regard to loss of biodiversity completed and synthesized**

*MTP Output Target 2007 8.1.1: Synthesis of soil fertility research in the Sudano-Sahelian zone completed*

A synthesis of soil fertility research in the Sudano-Sahelian zone has been written up in a book entitled “Soil Fertility Management in the Sudano-Sahelian Zone of West Africa: Agro-Economic Evaluation of Soil Fertility Restoration Options”. This book is now in press. It covers several years of research by DMP partners, other collaborators and the effort led by Dr Andre Bationo.

The book contains seven chapters. Chapter 1 presents an overview of the Sudano-Sahelian Zone of West Africa where the general characteristics of this region are discussed. Chapter 2 discusses the use and management of nitrogen sources. The effects of different cropping systems on soil fertility management and the sources and management of phosphorus resources in the region are discussed in Chapters 3 and 4 respectively. The book proceeds to discuss the importance of organic resource management in the sandy Sahelian soils (Chapter 5) and the onfarm evaluation of soil fertility restoration technologies (Chapter 6). The book concludes by highlighting future research needs (Chapter 7).

This synthesis highlights that the majority of the population in Sudano-Sahelian Zone of West Africa (SSZWA) is small-scale resource-poor farmers who rely mainly on rain-fed agriculture for their livelihoods. However, rainfall in this region is erratic, poorly distributed and quite variable, which make rain-fed agriculture a risky enterprise. Furthermore, the increasing population, livestock pressure and growing competition over the use of water for generating hydroelectricity and other uses are contributing to water becoming a scarce resource. Declining water quantity and quality, increasing soil degradation and inappropriate crop-management methods limit agricultural productivity, making food security a major concern.

Research in the region has shown that a win-win situation can occur when systems research integrates germplasm, crop, nutrient and water management, with an explicit focus on empowering farmers and rural communities to take advantage of market opportunities to raise their incomes. There is an urgent need to develop and use such approaches and tools to develop, evaluate, adapt and scale up the improved technology options for enhanced water and nutrient-use efficiency.

The lessons learnt from this book will benefit the work of a wide group of researchers, development practitioners and students not only in the SSZWA but the continent as a whole, including those that focus their work on agriculture, livestock and natural resource management.

In addition, the characterization of benchmark sites is being published in a book and will bring out the major soil fertility issues in the desert margins of Africa as well as the land degradation and biodiversity issues. Project coordinators in all participating 9 DMP countries in collaboration with a multi-disciplinary team of researchers and development partners carried out bench mark site characterization and collected information and data on both the socio-economic and physical environments. The information and data collected by the various teams have been synthesized and discussed within the DMP Group. A sub-committee of the DMP Steering Committee (SC) was set up to provide guidance on the form and content of the planned book in light of available information and data. The suggestions of the sub-committee were reviewed by the full SC and the following decisions were taken.

Tentative Book Title: Responding to land degradation and biodiversity losses in Sub-Saharan Africa dry lands.

Book Structure and Content. Agreement was reached on the following: In addition to a foreword and a preface the book will contain the following six chapters:



- i) The DMP: A brief description of the DMP linked to the objective of the book and contextualized within current issues of global importance.
- ii) The people and their environment. A bio-physical and socio-economic description and analysis of the benchmark sites.
- iii) Land degradation and biodiversity losses. An analysis of the causes, type and extent in benchmark sites and the impact on livelihood
- iv) Towards win-win options for improved NRM and livelihoods in the SSA desert margins. A presentation of INRM and alternative livelihood options developed and tested in benchmark sites
- v) Enabling environment for increased impact. Policies, institutions, information sharing, scaling up and capacity building imperatives to ensure sustainable impact of remedial actions taken to reverse land degradation and loss of biodiversity.
- vi) Conclusions and lessons learned. Key messages placed within the context of current global issues including climate change.

Lead authors and Coordinating lead authors were assigned to each of the chapters.

Deadlines: Under the guidance of an experienced publisher (Green Ink Publishing Services), realistic deadlines were set for the various steps from the preparation of various drafts through clearance by both UNEP and ICRISAT to publishing and distribution. Under this scenario, the book is expected to be published by February 2009.

**Output 8.2. Crop, tree and livestock integration strategies incorporating enhanced water and nutrient use techniques with appropriate capacity building measures developed and promoted for agro-diversity management, commercialization of agricultural enterprises and improved human and livestock health. Knowledge shared and strategies formalized**

*MTP Output Target 2007 8.2.1: Training on biodiversity management strategies and assessment monitoring to 50 NGO and CSO groups in SSA completed*

A biodiversity assessment manual has been developed and published by ICRAF: Kalinganire *et al.* (editors). 2005. Caractérisation de la biodiversité ligneuse dans les zones en marge du désert: manuel de procédures. ICRAF occasional Paper no.3. Nairobi: World Agroforestry Centre. A data analysis workshop was organized with participants from Burkina Faso, Mali, Niger and Senegal.

In the Suid Bokkeveld target area of South Africa, the focus is on conserving biodiversity and other natural resources, as well as enhancing livelihoods of small-scale rooibos tea (*Aspalathus linearis*) farmers. Rooibos tea is a medicinal drink made from the rooibos tea shrub. Research on sustainable harvesting of rooibos undertaken in Phase I of the project led to an inventory of endemic sub-species of *Aspalathus linearis* being undertaken, including GIS co-ordinates of significant populations (Phase II). A 2-day training course on the theory and practice of GIS data collection was held for 16 local data collectors from the local community and a manual has been written for the use by small-scale farmers. The trainees simultaneously recorded data in 4 areas, ie, Kleinvlei (including Agterstevlei, Brugkraal, Grasvlei), Heuningvlei (including Heiveld, etc.), Beukeskraal (including Langboome, Nuweplaas, Vaalheuning) and Eselbank (including Langkloof and Marthinsrus). The data was downloaded and a full set of GIS maps has been created for the Wupperthal Rooibos Tea Association, and the organic certifying body, Lacon. The further development and use of the GIS as a management tool by local land users and service provider will depend on further funding being made available. Participatory land use planning with farmers minimised negative impacts of farming practices on endemic populations of *Aspalathus linearis* on the farm Matarachope. It also provides an example of effective collaboration to enhance production with minimal impact. Climate change adaptation focused on increasing the resilience of small-scale tea farmers in responding to climate change. Farmer focus groups used a decision/activity calendar methodology, and met iteratively to identify the impacts of climate extremes on rooibos tea (*Aspalathus linearis*) farming systems. This enabled the identification of existing and desired adaptation measures and the identification of gaps (institutional, training, knowledge) in farmers' ability to undertake suitable adaptation strategies in the light of climate risk. Endemic (wild) populations, as well as cultivated fields of rooibos tea, were monitored and periodic assessments of their status in terms of resilience to climate risk, and to pests and pathogens were undertaken. Farmers worked with researchers to monitor on-farm climate conditions (through keeping rainfall records), climate impacts on farming (measuring plant growth) and identify successful adaptation strategies. Climate conditions, impacts and adaptation strategy track records are reported on and documented regularly (this is a "best practice" case). The work on climate change led to the Heiveld Co-operative developing a

sustainable land management project, funded by the GEF Small Grants Project. “Best bet” soil conservation technologies based on local knowledge nurtured by the project in Phase I have been scaled-up. Two Mentor Farmers are employed by the Co-operative to provide extension advice and production support to members of the Suid Bokkeveld community, and in turn receive regular mentorship from the project staff.

The rangelands are home to many important plant species, which contribute to the daily sustenance of the local communities. These plants provide forage, fuel wood, fibres, dyes and resins and significantly contribute to food security. Food from the wide range of traditional food plants makes supplemental, seasonal and emergency contributions to household food supply. Furthermore, the rangeland vegetation is a genetic reservoir of numerous plants, which presently contribute strongly to economic development or have the potential of doing so. However majority of the communities in the ASALs have not exploited the full potential of these resources especially in value addition of the products. The DMP has carried out a study to identify important locally available plants with nutritional, medicinal, cosmetic and other uses, their marketing systems and plant population trends as well as reasons for the trends.

Community meetings were held at Kalii, Kathyaka and Kasayani sub-locations in Makindu Division of Kibwezi district. Participants were stratified into four different groups; men under 45 years of age and those above 45 and similarly to the women. Each group then listed and ranked the different types of plants utilized by the community for 5 main uses ie, as food (fruits and vegetables), medicinal, cosmetics and others (basketry, ropes, dyes, etc.) with the guidance of a questionnaire.

*Adansonia digitata* was the most important fruit tree in all the sites. Other than the fruits, the bark is also used for roofing and making temporary structures while fiber from the trunk is used as strings and for weaving ropes and baskets. With exception of men over 45 years, all groups in all sites indicated that the plant population for *Adansonia digitata* has been declining due to clearing for cultivation, destruction by elephants, use as livestock feeds, poor germination and drought. *Tamarindus indica* and *Berchemia discolor* were ranked second and third important fruit trees respectively. *Kedrostis pseudogijef* and *Amaranthus hybridus* were ranked first and second, respectively, as important vegetable plants. Their availability is mainly dependent on wet seasons. There was significant variation in the highly valued type of vegetables between Kalii and the other two sites. Kalii is drier than the other two sites hence supports a different range of vegetable plant species. *Ocimum suave* was the most important plant used as cosmetic. The plant is currently used as mosquito repellent in most homesteads. The leaves and seeds are used for human medicine too. Plants for medicinal value varied across the sites and between the groups. Importance was based on the severity of the diseases or on the variety of diseases it treats while others could not rank but were only listed. *Zanthoxylum chalybea*, *Solanum incanum*, *Terminalia brownii* and *Aloe* sp. (Kiluma) featured as important plants at different levels of ranking in the 3 sites.

Communities still depend on various plants species for subsistence in terms of food, medicine and cosmetics. Though some plants were being exploited commercially, the potential has not been fully exploited either through promotion or value addition.

The biodiversity garden of the desert in Mali has been enhanced by the introduction of new grass and shrub species including the following: *Combretum glutinosum*, *Parkia biglobosa*, *Tamarindus indica*, *Acacia leata*, *Cassia sieberiana*, *Piliostigma reticulatum*, *Combretum aculeatum*, *Leptadenia pyrotechnica*, *Pergularia tomentosum*, *Commiphora africana*, *Combretum micrathum*, *Blepharis linearifolia*, *Euphorbia balsamifera*, *Sclerocarya birrea* *Cenchrus biflorus* and *Panicum leatum*. Several NGOs and CSO groups underwent some training in the management of the biodiversity within the biodiversity garden.

*MTP Output Target 2007 8.2.2: Training on LLM and FIRM given to partners in ESA.*

Project leaders and scientists who are responsible for the DMP projects in South Africa, also attended some training and capacity building workshops themselves. These include the Participatory Research and Scaling Up course (Kenya), a Training Course on Knowledge Sharing with Resource Custodians (South Africa), Local Level Monitoring (LLM) course (Namibia), the Forum for Integrated Management (FIRM) initiative (Namibia), and a course on Environmental Law for Environmental Managers.

In Namibia, the training focused on enhancing the capacity of resources users and service providers at local level to sustainably manage their natural resources. This includes both training (technical and organisational) and institution-building at grassroots level. Putting communities at the centre of their own development process

is a cliché commonly used amongst the development community. Multi-sectoral and/or inter-sectoral support to community-based organisations (CBOs) is another customary dictum of service delivery organizations. Namibia's Programme to Combat Desertification (Napcod) developed and tested a model for integrated resource management at local level. This model is called the "*Forum for Integrated Resource Management (FIRM)*", and was adapted in five pilot areas of DMP Namibia. Local Development Committees (LDCs) in 5 pilot areas agreed to be supported by the DMP Namibia in the establishment and functioning of FIRMs in their areas. These areas are Okakarara, Okondjatu, Okamatapati, Koblenz and Otjituu.

The enabling environment for environmental and development work in Namibia brought a multitude of projects and organizations often active within the same area and working with the same community of people, causing confusion with different timeframes, objectives and activities. This uncertainty can be overcome by an approach such as FIRM. By pooling resources, working through a single community based organization and cooperation, the efforts of all stakeholders can be directed by the needs of the community as articulated by the CBO at a pace the community is comfortable with.

This community driven approach empowers community decision-making, provides opportunities of capacity building and ensures community control over developments, provided that all other stakeholders take a more passive role, helping only when approached. Donors, government organizations, service organizations and NGOs need to become more flexible in their approach to planning and implementation, their timeframes and definitions of success.

A six-member DMP team from Botswana traveled to Gobabeb Research and Training Centre, Namibia for a week's training workshop on the Forum for Integrated Resource Management (FIRM) and Local Level Monitoring (LLM) participatory approaches. FIRM is an approach to ensure that rural communities are in charge of their own development. It involves a community based organization of rural farmers taking the lead in organizing, planning and monitoring their own activities and development actions while coordinating the interventions of their service providers. These varied service providers may take the form of traditional authorities, government departments, NGOs and projects.

Upon return from Namibia, meetings were organized and held in the project villages of Mathathane, Motlhabaneng and Tsetsebjwe in Bobirwa sub-district, and at Maubelo and Tshane in Kgalagadi district to sensitize communities on the concept of FIRM. After acceptance of the FIRM concept by the communities, they proceeded to elect members of the FIRM Management Committees. Follow-up meetings were held to develop Terms of Reference (ToRs) for respective FIRM Management Committees. One other major activity in the establishment of FIRM was the conduct of workshops for the communities to develop integrated work plans for each of the five villages. Monitoring of implementation of the agreed work plans is on-going.

FIRM is now well established for the communities of Mathathane, Motlhabaneng, Tsetsebjwe, Maubelo and Tshane villages. FIRM Management committees have been put in place in each of the villages, and ToRs for the respective FIRM Management committees have been developed. Integrated work plans have been developed in each of the villages.

LLM showed a pronounced impact on the area of degraded land that has been abandoned or rested in Kgalagadi District (sandveld) compared to that in Bobirwa Sub-district (hardveld). This is partly due to severe rangeland degradation in the sandveld and partly owing to the resourcefulness of the FIRM Management Committees of Maubelo and Tshane villages. It is hoped that the LLM tool will yield better results when relevant indicators of rangeland conditions (currently being developed) have been established, and local monitoring programmes are put into place.

## **Project 9:**

### **Poverty alleviation and sustainable management of land, water, livestock and forest resources through sustainable agro-ecological intensification in low- and high-potential environments in the semi-arid tropics of Africa and Asia**

**Output 9.1. New tools and methods for management of multiple use landscapes and climatic variability with a focus on sustainable productivity enhancement, developed and promoted with associated capacity building in collaboration with NARES partners in Africa and Asia**

*Output Target 2007*

*9.1.1 Mechanistic model adapted for spatial simulation of African sorghum/millet phenology and biomass partitioning. Model released, along with updated genotype databases and simplified framework for extrapolating variety performance to larger recommendation domains*

#### **Activity 9.1.1.1: Endorsement of improved phenology modules by DSSAT development team and incorporation for release**

Purpose. DSSAT is one of the leading cropping systems models with a large and growing suite of modules including CERES-Sorghum and CERES-Millet. DSSAT's plant growth, phenology and physiology components are arguably the most detailed amongst comparable systems-level simulation platforms. Yet, they display limited performance when simulating development and growth in a significant number of WCA landraces. This shortcoming is likely to delay model-assisted genetic improvement of crops in the region and subsequent adoption levels.

Background. West African sorghum and millet landraces can display large differences from exotic varieties, notably on plant development. Photoperiod sensitivity covers a much wider range of values, up to one order of magnitude larger than the most sensitive of Indian germplasm reported in crop model databases. We developed an improved phenology routine based on a hyperbolic response of thermal time requirements to daylength (Folliard et al. 2004) for incorporation in DSSAT and other cropping systems models. A parallel version of CERES-Sorghum was developed, compiled and validated using WCA data. It was not incorporated in DSSAT v. 4.0.2 for release and kept separate for further investigation. More collaborative work was needed to raise awareness about the value of the improved model.

Methodology. Increased collaboration was initiated with Dr. Jeff White who revived and enlarged the DSSAT sorghum modeling group. Two independent simulation experiments were conducted with the original, linear-cumulative response and the improved, threshold-hyperbolic response. The simulation dataset was expanded from the demonstration CSM388 cultivar in Folliard et al. to include 13 sorghum and millet varieties from 15 planting date experiments in 6 sites, covering a range of latitudes and photoperiod sensitivities (table 9.1.1.1).

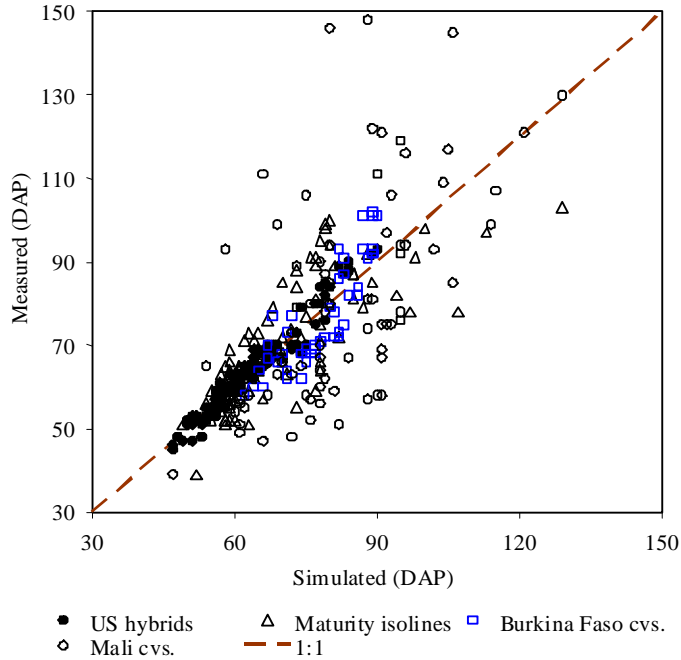
Results. Fifty-four cultivars representing four groups of sorghum germplasm were calibrated assuming a 12 h critical daylength and varying only the duration of the juvenile phase and photoperiod sensitivity (Fig. 9.1.1.1.1). Simulations of days to anthesis with the original model showed good prediction for a set of 17 US hybrids grown in Arizona ( $r^2 = .95^{**}$ , RMSE = 3 d), but poor agreement for a set of highly photoperiod sensitive cultivars from Mali ( $r^2 = .40^{**}$ , RMSE = 22 d), as is shown in Figure 9.1.1.1.2. For eight maturity isolines varying in photoperiod sensitivity (Quinby 1973), simulations of the most sensitive lines also were problematic ( $r^2 = .63^{**}$ , RMSE = 8 d), but germplasm from Burkina Faso, which presumably would also be highly sensitive, were simulated reasonably well ( $r^2 = .73^{**}$ , RMSE = 7 d) - suggesting, in fact, lower PP-sensitivities as in improved germplasm. Application of the new model on Mali data significantly improved  $r^2$  and RMSE values (from .37 to .88, 26 to 12d respectively). These results confirmed the need for caution when applying DSSAT in tropical environments since the current photoperiod response may not handle all photoperiod sensitive germplasm adequately. Results raised awareness on the need to incorporate the new model, which is endorsed as an option.

Next steps. Release of DSSAT v. 4.5 is confirmed for May 2008 and will include the new phenology model in both CERES-Sorghum and CERES-Millet. Simulations of growth and grain yield appeared unreliable due to incorrect timing of partitioning to stem and leaf growth, and biomass partitioning improvements are underway. These problems appear readily addressable, and their resolution would greatly enhance the utility of the model

for examining questions such as what are likely effects of maturity type and water use over planting dates in both temperate and tropical systems This is particularly important in view of expected climate change impacts on the structure of the seasons.

**Table 9.1.1.1. Examples of WCA sorghum and millet germplasm incorporated in expanded simulation work and DSSAT genotype database. The smaller the difference (Pbase-Psat), the stronger the photoperiod sensitivity**

| Cultivar name | Description                                                                                                                        | Psat (hrs) | Pbase (hrs) |
|---------------|------------------------------------------------------------------------------------------------------------------------------------|------------|-------------|
| CSM219        | Sorghum Guinea, origin: Segou, avg. cycle 110 d., very tall, landrace                                                              | 13.3       | 13.6        |
| CSM63         | Sorghum Guinea, origin: Kayes, avg. cycle 80 d., very tall, improved landrace                                                      | 13.4       | 15.3        |
| Jebana        | Sorghum Durra, origin: Segou, avg. cycle 120 d., moderately tall, landrace (also called <i>niofiento</i> )                         | 12.6       | 13.8        |
| E35-1         | Sorghum Caudatum Zera Zera, origin: Ethiopia, avg. cycle 90 d., improved landrace                                                  | 12.6       | 14.7        |
| CSM388        | Sorghum Guinea, origin: Koutiala, avg. cycle 125 d., very tall, improved landrace                                                  | 13.1       | 13.6        |
| IRAT204       | Sorghum Caudatum, avg. cycle 80 d., short, improved variety                                                                        | 12.9       | 15.8        |
| M9D3          | Millet, avg. cycle 110 d., very tall, improved landrace                                                                            | 13.0       | 13.8        |
| Nazongala     | Sorghum Guinea, origin: Ouagadougou, avg. cycle 110 d., very tall, improved landrace                                               | 13.1       | 13.7        |
| Sanioba03     | Millet, origin: Koutiala, avg. cycle 115 d., very tall, improved landrace (also registered as <i>CMDT03</i> )                      | 13.0       | 13.8        |
| SaniobaB      | Millet, origin: Loulouni, avg. cycle 150 d., very tall, landrace (also called <i>sanko</i> – ie, “after the rains”)                | 12.7       | 13.0        |
| Wasulu        | Sorghum Guinea, origin: Loulouni, avg. cycle 155 d., very tall, landrace                                                           | 12.5       | 13.0        |
| W33           | Sorghum Guinea, origin: southern Mali, avg. cycle 140 d., tall, landrace (also called <i>kende-ngu</i> )                           | 12.8       | 13.3        |
| Surukuku      | Sorghum Caudatum, origin: Loulouni, avg. cycle 150 d., short/dwarf (believed to be millet by farmers b/c of very compact panicles) | 12.0       | 13.4        |



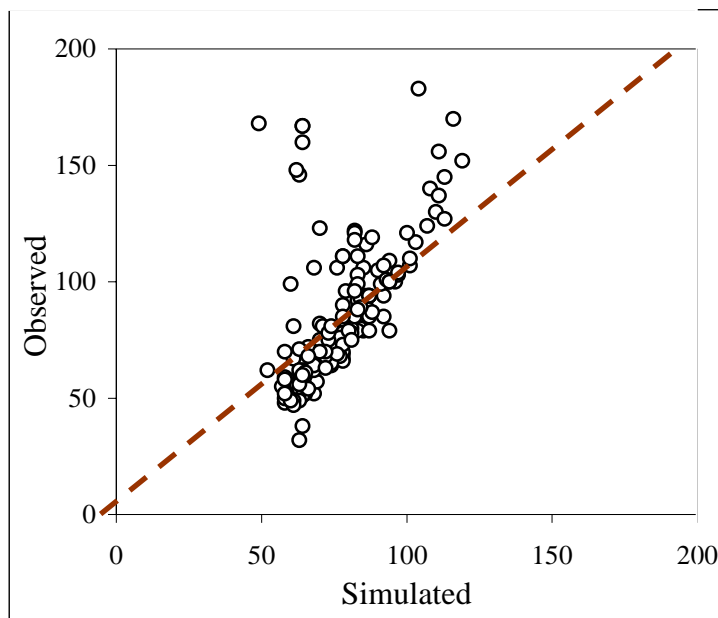
**Figure 9.1.1.1.1. Comparison of measured vs. simulated days to anthesis for four groups of germplasm. Original CERES-Sorghum model (linear cumulative response). Highly photoperiod sensitive material from Mali displays largest departures from 1:1 line**

(a) Cumulative linear

(CERES original)

$$R^2 = 0.37$$

$$RMSE = 25.7$$

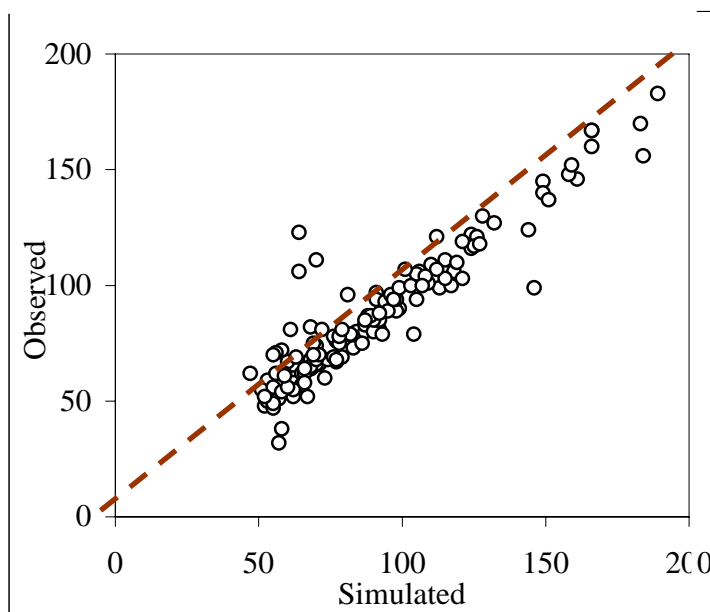


(b) Threshold hyperbolic

(Folliard et al. 2004)

$$R^2 = 0.88$$

$$RMSE = 11.6$$



**Figure 9.1.1.1.2. a) Days to anthesis computed on the Mali cultivars using the original CERES-Sorghum and improved models. b) Reliance on improved threshold-hyperbolic response allows the simulation of delayed cycles subsequent to early sowing.**

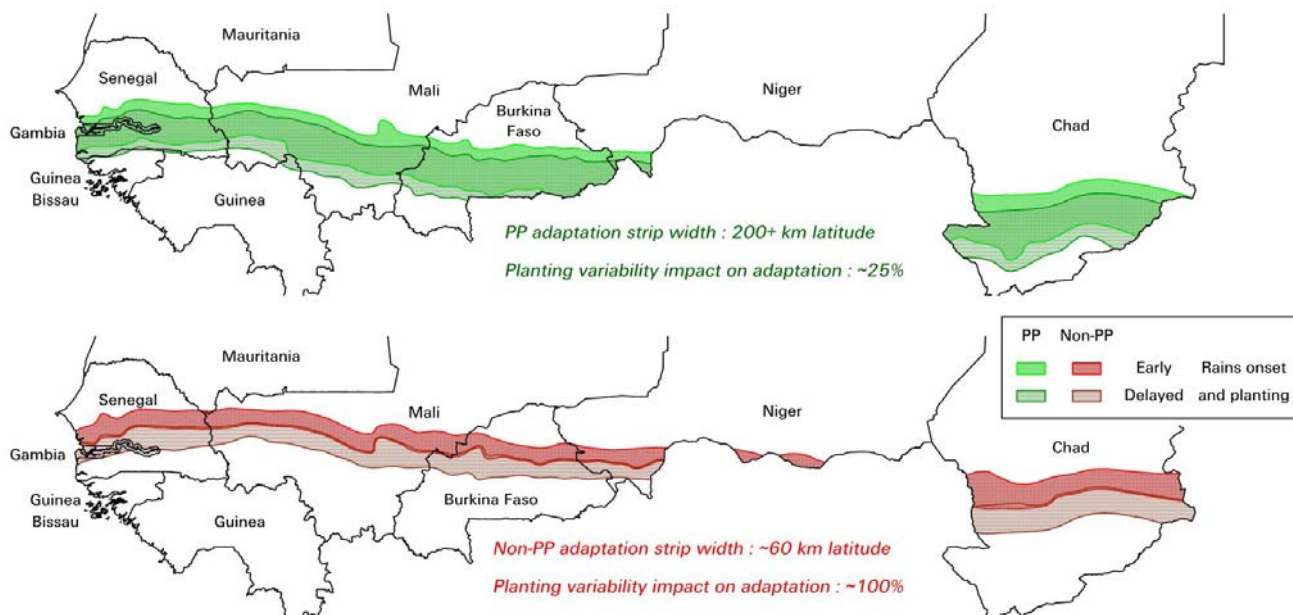
**Activity 9.1.1.2: Beyond Length of Growing Period – improving criteria for varietal adaptation mapping on regional scales, with focus on WCA**

**Purpose.** Determination of recommendation domains has long focused on a species level and relied on average “normal” climate conditions (LGP: average length of growing period) and large-scale concepts of homogeneity like mega-environments. Here we utilize learnings from crop simulation models to devise alternate cultivar-level mapping methods based on more relevant phenological adaptation criteria, such as end of growing season dates.

**Background.** Photoperiod sensitivity allows sorghum and millet landraces to match cycle duration with the expected length of the growing season. Mechanistic crop models can be used to understand and simulate G by E by M interactions. Results of sensitivity analyses allow the identification of main performance factors at various levels of scale. In turn, acceptable model simplifications can be devised for analysis of adaptation and potential adoption (eg, recommendation domain mapping). On regional scales, determinants of phenology (plant development) are the most important factors. They are relatively more important than determinants of biomass partitioning (plant growth) especially in smallscale farming where risk management largely relies on production stability. Fixing crop cycles on normal LGP often carries unacceptable risk and is potentially dangerous in variable climates, as indicated by widespread PP-sensitivity in native plants. Mapping methods for out/upscaling must reflect this diversity to limit rejection of improved, but in adapted germplasm.

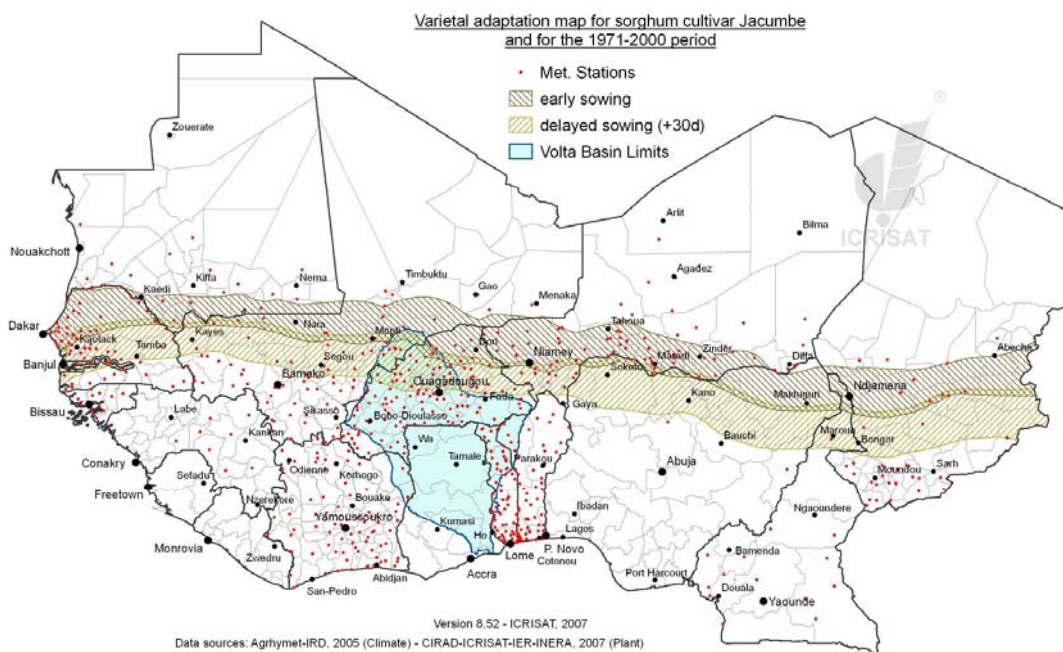
**Methodology.** A phenological adaptation index was defined that allows fast delineation of optimal cultivation zones for both PP-sensitive and PP-insensitive material. In WCA regions of modal rainfall, a cultivar can be considered adapted if it flowers about 20 days, on average, before the end of rains. Adaptation maps based on that criterion do take into account the uncertainty in sowing dates characteristic of the region (as opposed to the technique of matching cycle duration to LGP, which does not). For computation of end-of-season dates, existing ICRISAT rainfall datasets (ex-Sivakumar, Climbase) were supplemented with third-party data from selected weather services and IRD (HydrAccess), for a total of 658 ground stations. Start and end of season dates were computed with a simplified water balance budget (Traoré et al., 2000), first on Mali datasets, then Mali+Burkina Faso, then the whole WCA region. An index based on the time lapse between flag leaf expansion and end of rainy season date was computed for all 658 ground stations, and spatialized using kriging.

**Results.** Figure 9.1.1.2.1 displays adaptation zones for two generic cases, PP-sensitive (in green) and weakly PP-sensitive or PP-insensitive (in red). For the early maturing red variety, the adaptation strip migrates rapidly southwards when sowing is delayed with the (unpredictable) onset of rains. Contrastingly, the photoperiodic green variety exhibits a slower shift with high degree of overlap between two distant sowing dates. The early maturing cultivar features large geographic adaptation, *provided that the onset of the season and sowing date can be predicted*. With delayed planting, it can cater to most of CILSS agricultural regions (Sahelian and Sudanian and North Guinean). However it features weak temporal adaptation for any given site. Conversely, the PP-sensitive cultivar can espouse temporal vagaries in climate, but is indentured to a specific agroecology (Sudanian or North Guinean). The width of the overlapping zone is indicative of the capacity of the crop to deliver on a wide range of planting dates – an interesting feature in variable and changing climates. This approach was applied to a first batch of 24 typical sorghum and millet varieties, as illustrated on PP-insensitive Jacumbe and PP-sensitive Kaura (Figure 9.1.1.2.2) for the entire WCA region. 400+ sorghum and millet varieties characterized as part of BMZ and other projects have been incorporated in a GIS environment.

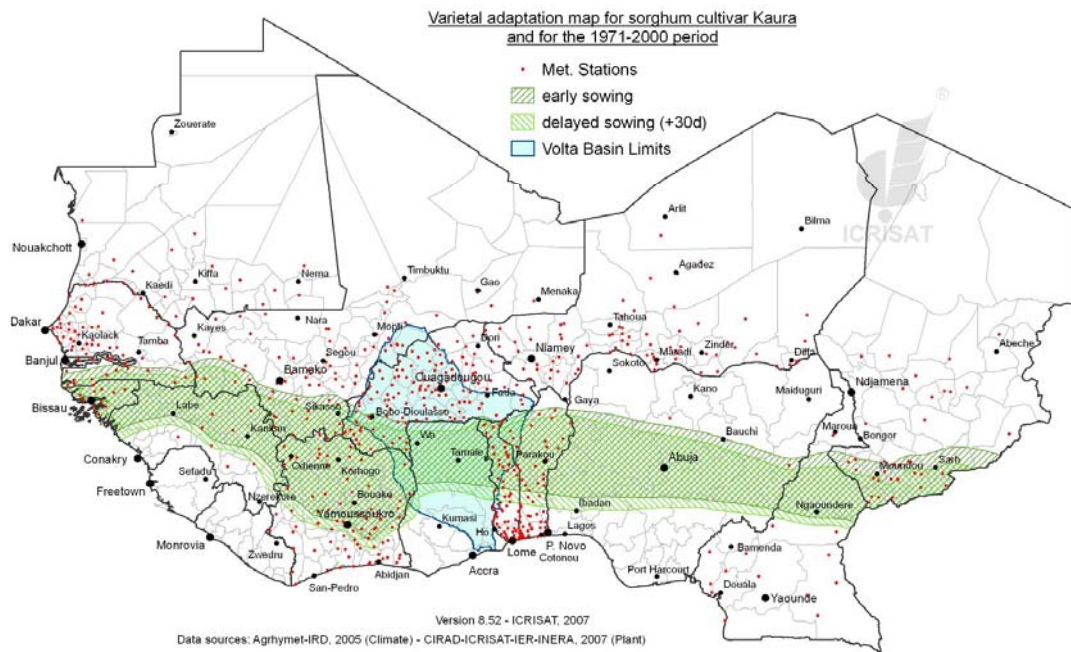


**Figure 9.1.1.2.1. Intertwined spatial and temporal dimensions of adaptation – illustration with generic PP-sensitive and PP-insensitive material (CILSS countries).**

Next steps. A new portfolio of climate change adaptation projects in development with IDRC, BMZ and leading climate modeling groups (SECC) will address the preparation of higher-level climate products for WCA, such as improved season onset prediction skill and decadal (10-year) projections, and their incorporation in varietal adaptation mapping frameworks.







**Figure 9.1.1.2.2. Application of end-of-season adaptation mapping criterion on large germplasm collections from WCA. Illustration for (a) PP-insensitive Jacumbe and (b) PP-sensitive Kaura**

## *Annual Milestones in 2007*

### **Activity 9.1.2.1 Implementation of Good Agricultural Practice: Interaction between farmers and agricultural concession companies supported through accelerated technology exchange in Mozambique (2007)**

The Mozambican government has been allocating geographic concessions to companies in various regions of the country, through a system regulated by a legal framework developed by the Ministry of Agriculture. At present, this system is largely used by tobacco and cotton companies whose products have little commercial value before processing, a costly and generally centralized procedure. As a condition for granting concessionary rights, the government stipulates that companies must promote crop diversification and Good Agricultural Practices (GAPs) to ensure food security for farming families, and to conserve natural resources. However no indicators have been developed to ensure compliance, and there is a general feeling that small-scale farmers in tobacco and cotton production zones are contributing to the degradation of the natural resource base. The aim was the development of partnerships between the public and private sector to mobilize knowledge and technologies from public investments in research to support the implementation of Good Agricultural Practices (GAPs) through technology exchange. The project activities were implemented as pilot in the agro-ecological zones R10 and R7 of Nampula, Tete and Zambezia Provinces, and focused on the complementary crops used by the concession companies, namely: maize, groundnuts, pigeonpeas and soybeans. Chickpea was also introduced as a new crop for soil fertility improvement. Irish potatoes and selected multi-purpose trees were considered because of their importance in the area. Two simulation models were used-APSIM model for crop simulation and MarkSim model Climatic simulation.

*Major milestones and achievements of the project were: -*

- Establishment of a forum to develop an innovation system in support of market-oriented research and development for targeted crops;
- Development of farm enterprise budgets for targeted crops, varieties and management practices for R10 and R7;
- Demonstration of selected 'best bet' technologies to farmers, traders and agro-processors;
- Raise awareness amongst traders, agro-processors and the general farming population on the benefits from use of improved quality seed and complementary agricultural inputs;
- Strengthen the existing system for supply of basic seed on commercial terms to seed entrepreneurs;
- Commission an aflatoxin testing laboratory in Nampula.

In general, the simulation analysis provided valuable insights into the interaction of various biophysical factors on crop production and quality of the resource base. To some extent this analysis was constrained by the non-availability of the required data to properly calibrate and validate the model to local conditions. Hence, the results of this simulation analysis should be treated as indicative and caution should be exercised when making their interpretation, particularly because of the limitations in the data used.

Preliminary results from Land health diagnostic surveillance indicated that the soil physical constraints seem to be the primary problem, probably exacerbated by structural decline due to low organic matter on some soils, leaching of bases poses a risk to sustained cropping.

To enhance the commercial seed system, one seed processing and storage facility was constructed in Nampula province, and one storage facility for potatoes in Angonia district, Tete province.

An aflatoxin testing laboratory was acquired and installed at Agronomic Post of Nampula province, and IIAM senior staff was trained in India.

ICRISAT reinforced its partnership with personnel from other NARS (IIAM, INAM), DPA, DDA, concession companies, NGOs, private-sector traders, CGIAR Centres (ICRAF, CIAT, IITA and CIP) and Reading University.

*Activity 9.1.2.2 Enhancement of a rapid survey method for estimating annual livestock demographic rates in traditional farming systems. Augustine Ayantunde and Bruno Gerard*

The method "12mo" is a cross-sectional survey method based on retrospective interviews of the farmers and on their mental records of the livestock demography (over the last 12 months before the survey). This method has been developed for estimating the annual demographic parameters of ruminant livestock populations (goats, sheep, cattle and camels) at community, regional or national level: natural death, parturition, prolificacy, mortinatality (mortality at birth), intake and off-take rates. The cross-sectional interviews can be repeated each

year for assessing the between-years variability, which is a basic component of the risk for farmers. 12mo provides more approximate data than ear-tagged animal monitoring. It is quick, less costly and easier to implement, particularly in large areas and for pastoral herds. Moreover, it can be implemented *a posteriori* of unpredictable events such as droughts or outbreaks, providing essential data for assessing the impact of these shocks. The "Version 1" of the method has been calibrated and tested under DGCD project on Decision Support Systems for the Sahel in study sites in Niger in 2006. A field manual on this herd demographic survey tool has been published in 2007. The method was adopted by Niger's Ministry of Animal Resources in conducting livestock census in many regions of the country in 2007, and will be promoted throughout the Sahel in the coming years.

Richard Jones, Moses Siambi and Carlos Dominguez

### Activity 9.1.2.3 Modeling ruminant production in West Africa Sahel

The objective of this activity was to estimate animal performance in terms of live weight changes using different combination of local feed resources and the profit margins using ruminant production models such as RUMINANT model. Under DGCD project on Decision Support Systems for the Sahel, there had been a preliminary testing of RUMINANT model in March 2007 to predict live weight changes and profit margins using different combination of basal and supplementary feeds (See the Table 9.1.2.3.1). The validation of the model is planned for the next phase of DGCD project.

**Table 9.1.2.3.1. Example of preliminary testing of RUMINANT model for sheep fattening for 7 different feedings regimes in Zermou, Niger**

| Feed type                                    | R1  | R2   | R3   | R4  | R5   | R6   | Re7  |
|----------------------------------------------|-----|------|------|-----|------|------|------|
| Sorghum stover                               | 0.2 | 0.14 | 0.04 | 0   | 0.17 | 0.09 | 0    |
| Groundnut haulms                             | 0.2 | 0.3  | 0.4  | 0.5 | 0    | 0    | 0    |
| Cowpea hay                                   | 0   | 0    | 0    | 0   | 0.2  | 0.35 | 0.45 |
| Acacia leaves                                | 0.2 | 0.2  | 0.2  | 0.2 | 0.2  | 0.2  | 0.2  |
| Bush hay                                     | 0.2 | 0.2  | 0.2  | 0.2 | 0.2  | 0.2  | 0.2  |
| Average daily gain (g/day)                   | 30  | 40   | 50   | 70  | 20   | 40   | 30   |
| Estimated feed cost (CFA)                    | 42  | 52   | 59   | 70  | 57   | 84   | 100  |
| Production cost per g of weight gained (CFA) | 1.4 | 1.3  | 1.2  | 1.0 | 2.8  | 2.1  | 3.3  |

Feed cost is based on prices during the harvest season. Feed quantity is expressed in kg.

Ayantunde and Bruno Gerard

### Activity 9.1.2.4 Building capacity to undertake climate risk analyses in Eastern African

Climate information, including historical and real-time, is vital for the optimal management of agriculture and the natural resources on which agriculture depends. When properly integrated with the decision making process, climate information has the potential to moderate the effects of variable climate on food production and ecosystem functions. The need for such integration is more important now than ever due to the growing concern about climate change and its impacts on agriculture.

Historically, meteorological organizations have collected and are maintaining huge databases of climatic information. But, very little effort has gone to turn this data into useful information for use by research and developmental programs through in depth analysis and interpretation to study the relationships among weather, climate and agriculture. To some extent this is constrained by complex nature of the agricultural systems and lack of appropriate tools to properly quantify the relationships between climate and agricultural production. However, recent advances in our understanding of the agricultural systems coupled with those in the computing technology resulted in the development of a number of tools and methods that are extremely useful in conducting a detailed analysis on the soil-plant-climate systems.

ICRISAT has identified a set of three tools to analyze climate data and produce high-quality information and products tailored for agricultural applications and to quantify the relationships between climate, crop, soil and water resources for use in the strategic and tactical management of agricultural systems. The suite includes:

INSTAT - a statistical analytical tool with special features for analyzing climate data;

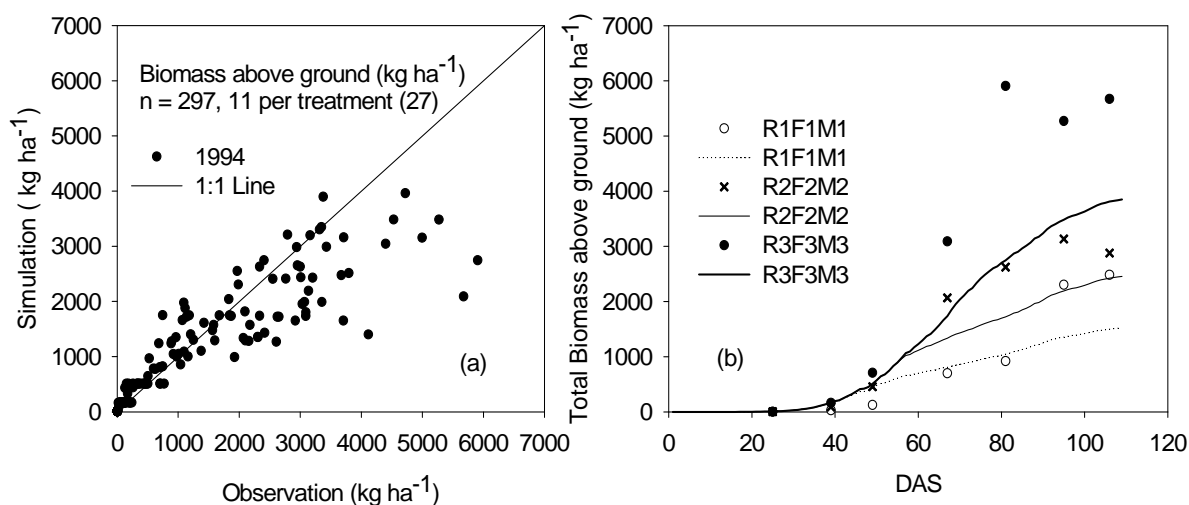
MARKSIM - a stochastic weather generator for generating synthetic daily weather data by estimating the third-order Markov model parameters from interpolated climate surfaces; and  
 APSIM – a modeling framework that provides capabilities via component modules to simulate cropping systems over variable time periods.

We are now working towards building a core team of research and extension experts with skills to make use of these tools. The skills will be built over a period of two to three years in each of the four participating countries. As a first step, 16 researchers from national agricultural and meteorological organizations of Ethiopia, Kenya, Sudan and Tanzania were trained to acquaint them with the application of these tools and test them as a part of the work under the two on-going projects on climate variability management supported by ASARECA CGS and IDRC CCAA. The researchers are now collecting the necessary data to calibrate and validate the models through experimentation and secondary data sources. After the completion of the data collection, a follow up workshop will be conducted during 2008-2009 to provide further insights into the use of these tools and calibrate and validate the models to simulate the management options relevant to their locations and generate products that are of local value.

KPC Rao and P Cooper

#### Activity 9.1.2.5 Modeling integrated fertility management strategies for pearl millet in the Sahel

Soil fertility and climate risks are hampering crop production in the Sahelian region. Because the high spatial and temporal variability of these two factors restricts the widespread applicability of research findings derived from experiments, crop growth simulation models could suitably complement experimental research to support decision making regarding soil fertility and water management. This paper reports on the testing of the millet (*Pennisetum glaucum* L.) module of the Agricultural Production Systems Simulator (APSIM) on a rainfed randomized complete block experiment combining, at three levels each, application of cattle manure (300, 900 and 2700 kg ha<sup>-1</sup>), millet residue (300, 900 and 2700 kg ha<sup>-1</sup>) and chemical fertilizer (no fertilizer, 15 kg N ha<sup>-1</sup> + 4.4 kg P ha<sup>-1</sup> and 45 kg N ha<sup>-1</sup> + 13.1 kg P ha<sup>-1</sup>) at ICRISAT Sahelian center, Niger during the 1994 and 1995 cropping seasons having contrasted rainfall conditions (Figure 9.1.2.5.1). Parameters describing leaf area expansion, phenology, radiation interception, biomass accumulation and partitioning, water dynamics, and



**Figure 9.1.2.5.1: Measured versus simulated biomass over time for all 27 treatments (a) and measured (dots) versus simulated (lines) change in millet biomass over time for three selected treatments (b) in an experiment of combined cattle manure, crop**

nitrogen accumulation were obtained from on-site experiments, from the literature or calibrated. APSIM simulations were in satisfactory agreement with the observed crop growth. Leaf area index was relatively well predicted. Simulated nitrogen stress was consistent with the fertilizer and rainfall conditions of the experiment. In terms of grain yield also the APSIM model performed fairly well ( $R^2 > 0.50$  and  $RMSE < 206$  kg ha<sup>-1</sup>). The model was able to adequately reproduce the overall higher observed grain yield in 1995 compared to 1994, despite the better rainfall in 1994. This emphasizes the importance of considering water – nutrient interactions even for environments for which water is (often wrongly) considered as the main constraint for crop production.

This research was presented at the 16<sup>th</sup> International Symposium of the International Scientific Centre for Fertilizers (CIEC). 16-19 September 2007. Ghent, Belgium by P Akponikpe, C Biolders, B Gérard and K Michels.

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**Activity 9.1.2.6 Estimation of climate risk reduction due to spatial dispersion of fields at the village scale**

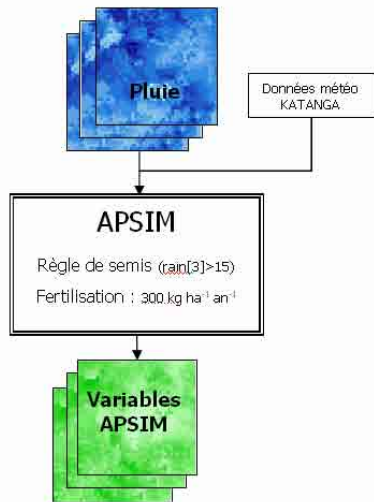
This research has the objective to evaluate the role of field spatial dispersion in reducing production risks linked to rainfall spatio-temporal variability. The development of a MatLab routine that integrated the APSIM crop growth model (parameterized for Sahelian conditions) and spatial inputs allowed to spatialized APSIM outputs on a grid basis at the landscape scale. The simulation work took advantage of the existing data sets of the Fakara region (one of the three benchmark sites of the project). Those data sets are:

- Spatial distribution of daily rainfall data series from a network of 60 rain gauges for the period 2000-2006;
- Daily weather parameters from Katanga automated weather station;
- Land allocation at the household level as mapped for the entire benchmark site by ILRI in 1996 (Hiernaux et al.) and for a sub-sample under this project in 2005 (Marinho).

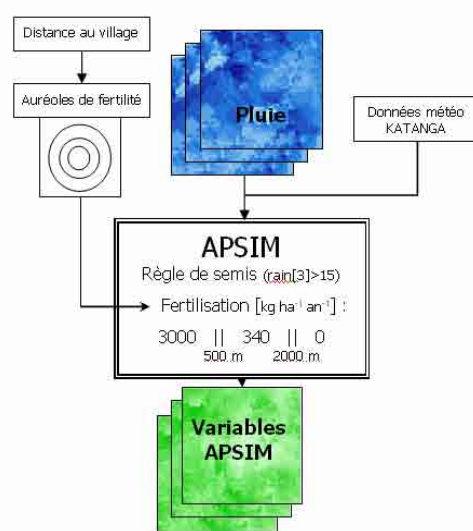
Grain yields at the field level and household level were obtained by GIS overlay analysis of land tenure map over yield grid outputs from APSIM (Figure 9.1.2.6.1). A risk indicator (rY) was then calculated per household as the standard deviation between household average yield for all its fields and the average yield for the study area for the years 1 to n:

$$rY = \sqrt{\frac{\sum_i^n (Y_i - \bar{Y})^2}{n-1}}$$

A)



B)



**Figure 9.1.2.6.1: Use of APSIM model to spatially estimate yields at the landscape scale: A) simple model with spatial distribution of daily rainfall from a network of 60 rain gauges and B) input of a fertility gradient around village as additional input.**

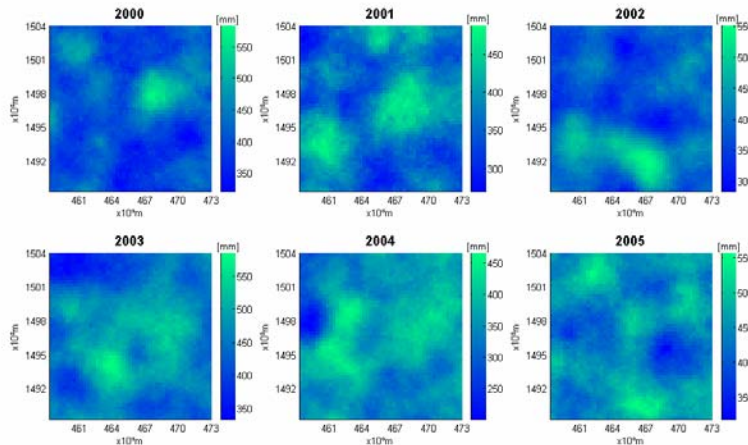
Field dispersion at the household level was estimated using the Convex Hull (area of the convex polygon whose vertices are some of the points in the input set). Relationship between the Convex Hull (dispersion of the household fields) and risk indicators were analyzed to check whether or not field dispersion reduced household production risks (Figure 9.1.2.6.2).

Results showed a slight reduction in risk with an increased dispersion of fields hinting that households with disperse fields are less vulnerable to climate and suffer less from yearly production fluctuation from climate variability.

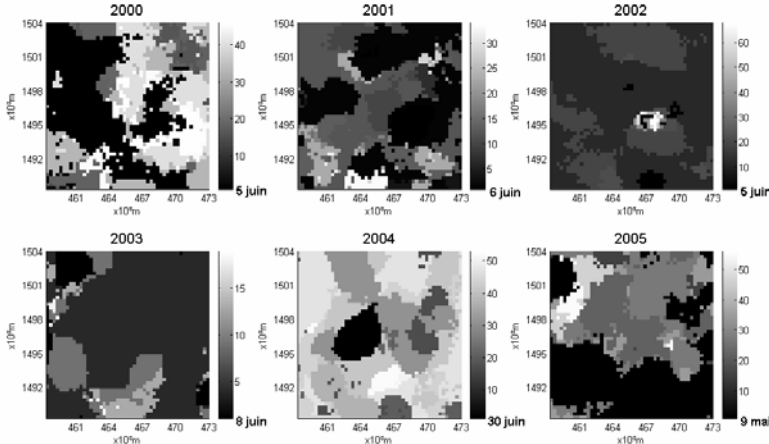
The thematic research on risk management showed the potential of combining crop growth models and spatial analysis at the landscape scale (Figure 9.1.2.6.). Tools developed in this study could be very useful to study nutrient dynamics at that scale. Further research in the area should take place in the submitted MARRS project.

For a more detailed presentation of this research, consult MSc Thesis of Julien Minet (Influence de la dispersion du parcellaire sur la gestion du risque climatique, UCL 2007).

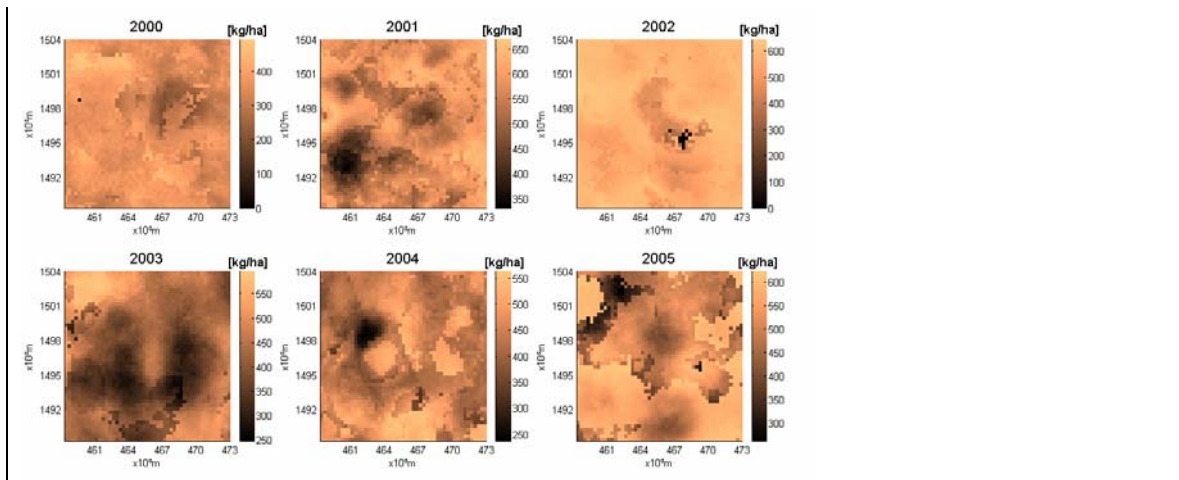
Cumulative rainfall for the rainy seasons 2000-2005. (daily rainfalls have been used as APSIM inputs)



Date of sowing spatially set as the first rain of the season larger than 15 mm

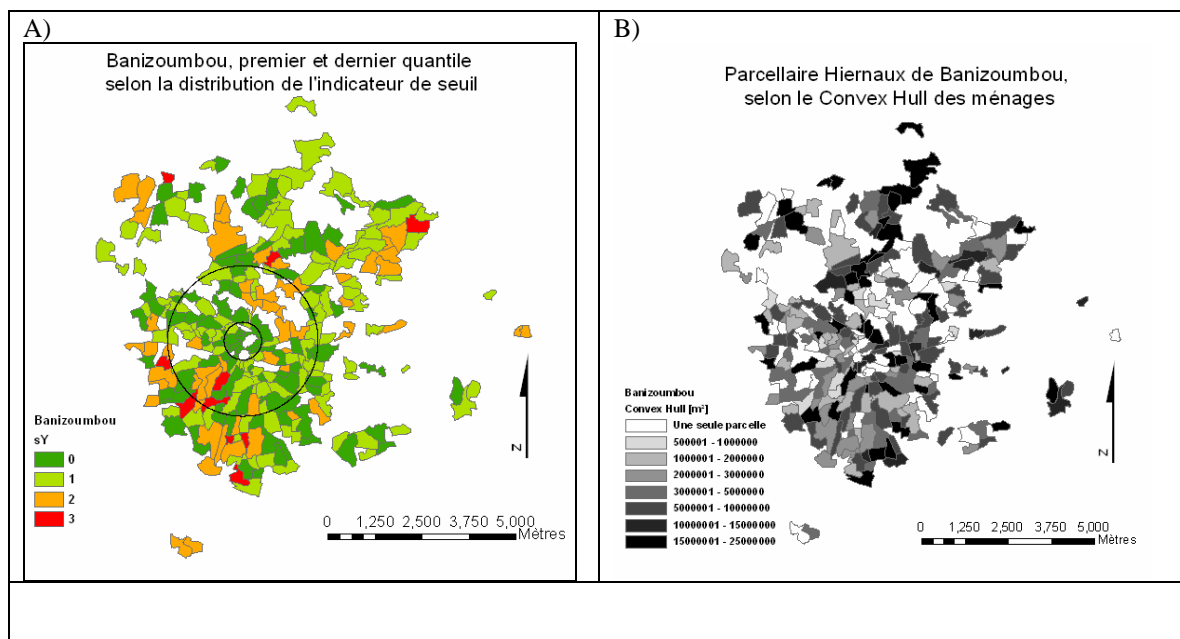


Grain yield maps



**Figure 91.2.6.2: Simulation inputs and outputs, additional output maps not shown here include LAI, total biomass and N leaching.**





**Figure 9.1.2.6.3: A) Yield thresholds at field level, double ring shows limit of high and medium fertility levels; B) Convex hull per household computed from the land tenure map.**

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#### Activity 9.1.2.7 Development of a methodology to better identify vulnerability

The proposed methodology has the objective to generate a food security indicator for the whole set of georeferenced Nigerian villages. First, a simple but reliable indicator extracted from the INS survey was constructed. Second, an econometric model was developed using GIS data as regressors. The fact that all regressors are observable at every point of the space ensures the applicability of the small area estimation (SAE) approach (Ghosh and Rao 1994) at the village level. Third, kriging (Schabenberger and Gotway 2005, pp. 226-232) was used to predict food security in non-surveyed villages, taking benefit from the spatial dependence of the phenomenon. Finally, predictions coming from the SAE approach and from kriging are merged through the Bayesian approach proposed by Bogaert and Fasbender (2006) to compose what we call an Econometric-Kriging-Bayesian (EKB) approach.

By listing up to 172 studies that seek to define and measure food security, Maxwell and Frankenberger (1992) didn't merely highlight the diversity of point of views and the complexity of the task but also induced the reader to the same conclusion of Maxwell et al. (1999) seven years later: there is a lack of 'gold standard' measure for food security, no definition or measure captures the concept accurately and completely. Indeed, even if most definitions are closely related with the World Bank's definition (1986,) which is the, "access by all people at all times to sufficient food for an active, healthy life", many problems can rise when trying to extract it from data.

Maxwell et al. (1999) showed that indicators derived from coping strategies can be reasonable proxies for consumption and expenditure variables. However, in our opinion, this result mostly relies on the fact that the indicators were tested from surveyed households within a geographically restricted and homogenous peri-urban area around Accra (Ghana). In the case of Niger, the weight attributed to each coping strategy should tremendously vary between ethnicities, food economy zones, according to the proximity to markets and cities and so on. Moreover, no ranking has been established by focus groups. So we tempted instead to extract some information from the limited but available consumption and expenditure variables. First, note that the calculation of the most common and probably desirable indicator, that is to say daily caloric intake, is not possible. Indeed, consumption variables only report the number of days that each product has been consumed during the last week while expenditure variables completely ignore auto-consumed quantities. Second, as already mentioned, habits, strategies and opportunities vary significantly across the vast Nigerian territory.



Consequently, the number of days that a household has consumed a given product can hardly be compared within our sample of villages. For instance, a Peul is expected, *ceteris paribus*, to consume meat and milk more often than a Hausa while the latter will probably consume more cereals. Given the absence of a reliable indicator, we decided to derive food security from an extremely simple proxy for food consumption and to evaluate the consistency of the econometric results by testing the same specification using the complex vulnerability index computed by the Institut National de Statistique (2006).

Our proxy variable groups together households in three classes, food secure, vulnerable and food insecure, using expenditures on sugar and/or on cooking oil during the last month. The idea comes from the fact that (i) sugar and cooking oil are complements to mostly of the dishes consumed in the country (they are proxies for food consumption), (ii) they are used in a similar way by each ethnic group (no ethnical bias), and (iii) they or their substitutes are rarely produced and consumed by the same household (no omitted quantities).

Preliminary results showed that vulnerability predictions are structured in space but can take into account local phenomenon, and their standard errors are smaller and more homogenous in space. On the other hand, the econometric approach showed that structural variables (roads, access to water, agro-pastoral systems) are extremely important determinants of food security, while a food crisis can continue to be felt one year later. The results also corroborate the idea that NDVI can be used as a proxy for agricultural production by establishing a link between remote sensing and food vulnerability. Detailed results will be presented in next year's report.

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#### Activity 9.1.2.8 Village Ecosystem and Society empirical Agent-based Model: testing social-driven forces on rural rainfed Nigérien millet-cropping farming system evolutions

The research objective was to describe, simulate and analyze the effects of social and agro-ecological constraints on rural farmers through the case study case of three different sites in rainfed Niger (Sahelian Africa) and test Boserup paradigm (Boserup, 1965). The work is based on a previous research on multi-agent model development for Sahelian rainfed systems which has shown that using such a model is a relevant approach to integrate the system's agro-ecological, social and economic characteristics. Moreover, family organizations and internal rules have strong impacts on village and environment evolutions and vice-versa. Two family transition processes are implemented in the model: family organizations can shift between a patriarchal mode and a non-cooperative one through family income redistribution tensions, which have strong effects on manpower and income allocations. Family inheritance systems can shift between "the traditional" customary mode and the Muslim one through family land availability tensions, which have strong effects on land allocations. We compare a scenario with no socially-driven evolutions and a scenario with the two implemented transition processes. Simulation results showed that:

- Agro-ecological and socio-economic characteristics have a strong impact on the local family type distribution and there by the allocation of resources between the production activities;
- New and more individualistic family types increase the robustness of the whole village population in the three simulated sites, through different and site-specific evolutions. An intensification gradient is observed from the most favoured site, where more intensive productions occurred and agro-ecological indices are bettered, to the less-favoured ones, where a large part of the population income come from migration remittances.

Bruno Gerard and the DGDC Improved Livelihoods in Sahel through the development and implementation of households bio-economics decision support systems project

#### Activity 9.1.2.9 Agroclimatic Characterization of Nucleus Watersheds in Karnataka

The SUJALA-ICRISAT Project nucleus watersheds are spread over 10 taluks in five districts of Karnataka. The five districts are characterized by hot summers with relatively pleasant winters. Watersheds in Dharwad and Haveri districts are under hot dry sub humid type, while those in the Tumkur taluk in Tumkur district, Chitradurga and Kolar districts fall under hot moist semi-arid type. Pavagada in Tumkur district experiences typical hot arid conditions.

Wide variation in the agroclimatic potential across the watersheds is observed (Table 9.1.2.9.1). Watersheds in Dharwad and Haveri districts receive a seasonal rainfall of about 500-600 mm. Bimodal rainfall distribution is observed; the first peak occurs from mid-July to 1<sup>st</sup> week of August and the second peak during mid of September to middle of October. Uni-model distribution of rainfall is seen in other watersheds. Watersheds in Kolar, parts of Tumkur and Chitradurga districts have a seasonal rainfall of about 500-670 mm with one peak of rainfall occurring during middle of September to end of October. Parts of Chitradurga district and Pavagada area in Tumkur district have a seasonal rainfall of about 400-500 mm with one peak of rainfall occurring during middle of September to end of October.

**Table 9.1.2.9.1 Variation of length of growing period (LGP) across nucleus watersheds**

| District    | Location    | Rainfed crop-growing period |        |                 |
|-------------|-------------|-----------------------------|--------|-----------------|
|             |             | Beginning                   | Ending | Duration (days) |
| Dharwad     | Hubli       | 10 Jun                      | 05 Dec | 180             |
| Haveri      | Haveri      | 10 Jun                      | 05 Dec | 180             |
|             | Ranebennur  | 25 Jun                      | 30 Nov | 160             |
| Chitradurga | Chitradurga | 05 Jul                      | 30 Nov | 145             |
|             | Hiriyur     | 20 Jul                      | 30 Nov | 130             |
| Kolar       | Kolar       | 10 Jul                      | 15 Dec | 155             |
|             | Gudibanda   | 01 Jul                      | 20 Dec | 170             |
|             | Sidlaghatta | 10 Jul                      | 20 Dec | 155             |
| Tumkur      | Tumkur      | 01 Jul                      | 15 Dec | 165             |
|             | Pavagada    | 20 Aug                      | 25 Nov | 95              |

Normal LGP varies greatly across watersheds, longest duration of about 180 days is available in Hubli and Haveri and shortest of about 95 days is available in Pavagada. There is more variation in the beginning of the growing period compared to the end. Watersheds in Kolar and Tumkur districts have more than six continuous weeks of wet conditions starting from September. At Hubli and Haveri, it is as early as 10 June and as late as 20 August at Kanakapura. It extends up to 20 December at Gudibanda and Sidlaghatta, ends by 25 November at Kanakapura.

Dharwad and Haveri districts have good potential for runoff water harvesting and structures while Chitradurga, Kolar and Tumkur have relatively lower water harvesting potential. Kanakapura has little scope for water harvesting. Only 47% of crop water requirements are met by rainfall as indicated by seasonal moisture adequacy index, crops often experience moisture stress and *in situ* moisture conservation measures play a greater role. Hiriyur has great risk of dry conditions during crop vegetative phase.

AVR Kesava Rao, SP Wani, K Krishnappa and BK Rajasekhara Rao

#### **Activity 9.1.2.10: Identifying Systems for Carbon Sequestration and Increased Productivity in Semi-arid Tropical Environments of Asia and the Middle East**

In the semi-arid tropics (SAT), low soil organic carbon (SOC) content and inappropriate management of water resources are associated with low crop yields. Besides SOC's importance for agricultural production, the accelerated decomposition of SOC contributes to the greenhouse effect, which is of serious environmental concern. Restoration of soil health through soil organic carbon (SOC) management is of crucial importance for tropical soil. Low SOC content in the SAT also provides an opportunity for sequestering more carbon in soil. However, the challenge is to identify sustainable C sequestration crops and management options. ICRISAT in collaboration with NARS from India (Central Research Institute for Dryland Agriculture, (CRIDA), Hyderabad) and Iran initiated several studies to study the impact of long-term legume based intercropping, rainfall,

deforestation, catena and different rainfed production systems on SOC. The salient findings from this research are as follows:

### *1. Impact of Long-term Improved Management on Soil Carbon Sequestration of Vertic Inceptisols in the Semi-arid Tropics of Central Peninsular India*

A long-term field experiment was initiated in rainy season of 1995 at the ICRISAT research station, Patancheru (78 16' longitude, 17 32' latitude and 540 m elev.), Andhra Pradesh, India. Experimental soils are Vertic Inceptisols from the Kasireddipalli series with a general slope of 2% and a variation in soil depth from 30 to 90 cm (depth of black soil). For the experiment, four hydrological units covering 15 ha were selected, depending on soil depth (90 to 50 cm and <50 cm) and system management (improved and traditional): 1) medium depth improved management, 2) medium depth traditional management, 3) shallow depth improved management and 4) shallow depth traditional management. Improved management comprised of sowing on broadbed-and-furrow landform and additions of nutrients through composted crop residues and pruning of *Gliricidia* (*Gliricidia sepium* (L.)) used as boundary hedges between plots; while traditional management consisted of sowing on flat land form and no addition of organic sources of nutrients. Each year, both management systems received 18 kg P ha<sup>-1</sup> as single superphosphate and the same pest control management.

From 1995 to 2004 rainy season, soybean/pigeonpea intercropped and soybean + chickpea sequential (rainy season: soybean; post-rainy season: chickpea), were grown. For the 2005 season, to enable improved nutrient management, the sequential cropping system was replaced with maize + safflower. Unfortunately, below average rainfalls in 2006 meant that the maize was replaced with sorghum. Each treatment (soil depth/management system/cropping system) is replicated three times in a split plot block design. For studying the SOC, MBC and other soil properties, on each replication, three cores were collected on diagonal to obtain depth-wise composite sample up to 90 cm (0-15, 15-30, 30-60 and 60-90) during December 2006 after soybean and sorghum harvest. For this study the data set is based on 96 composite samples analyzed following standard methods.

Results from this 11-year long-term experiment clearly show that soil depth and management practices interact to influence SOC. For the shallow soils (<50cm) management did not influence SOC, whilst improved management on medium depth soils (50-90 cm) increased SOC from 0.66% under traditional management to 1.2%. Irrespective of treatment and soil depth, surface layers (0-15 cm), as expected, had the highest levels of SOC, decreasing quickly with depth.

These findings have demonstrated that by adopting holistic approach with legume, land, water and nutrient management options potential of Vertic Inceptisols can be harnessed for sequestering C in soil along with increasing productivity for sustainable livelihoods.

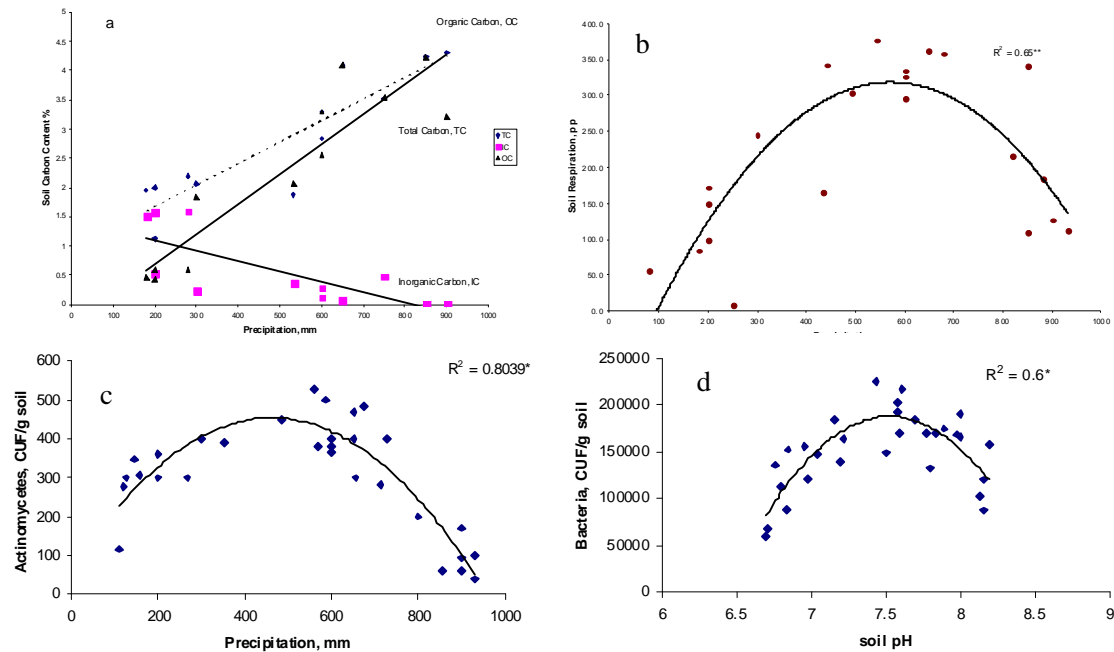
SP Wani, Vincent Richter, Ch Srinivasarao and Piara Singh

### *2. Carbon and Nitrogen Stocks of the Soils of Different Climatic Regions of Golestan Province Iran*

A south-north transect forming a climo-toposequence with fourteen soil profile observations starting from 150 mm precipitation in the northeast to over 900 mm in the heights of Alborz Mountain Ranges in southwest Iran were selected to study the soil carbon and nitrogen pools in different climatic regions. It has been postulated that aridity in the climate is responsible for the formation of pedogenic calcium bicarbonate and this is a reverse process to the enhancement of SOC. The soil moisture regimes varied from aridic to xeric and finally to udic from north to south. The soil temperature regime also varies from thermic in the northern parts to mesic in southern parts where the elevation reaches 2500 m. The parent material of all the soils is loess deposits. The studied soils were classified as Aridisols and Entisols in the aridic moisture regimes, Inceptisols and Mollisols in the xeric moisture regimes and Alfisols in the udic moisture regime regions. The results revealed that organic carbon and total nitrogen increased while inorganic carbon decreased with increasing precipitation. Total carbon did not show any significant variation with climate (Figure 9.1.2.10.1). Biological soil quality attributes such as soil respiration, biomass carbon and nitrogen increased sharply from aridic to xeric regions but decreased gradually in the udic regions. This trend was in accordance with the population of bacteria and actinomycetes. The xeric-thermic moisture and temperature regimes have provided favourable soil environment

with regard to the available moisture and temperature both for the population of microorganisms and also the vegetative cover both of which are responsible for the biomass production.

The organic carbon stock of the soils varied from 1.6 P g ha<sup>-1</sup> in the arid regions to 9 P g ha<sup>-1</sup> in the top one meter of the soils of humid regions. This was 5 g P ha<sup>-1</sup> of total carbon of soil in the arid soils and 9 g P ha<sup>-1</sup> of total carbon in humid regions.



**Figure 9.1.2.10.1. Variation of soil carbon (a); soil microbial respiration; (b) population of actinomycetes; (c) with precipitation and bacterial population with soil pH; (d) in the topsoil. The variation of TC was shown as average for the top 1m soil.**

The xeric-thermic moisture and temperature regimes has provided favourable soil environment with regard to the available moisture and temperature both for the population of microorganisms and also the vegetative cover which both are responsible for the biomass production.

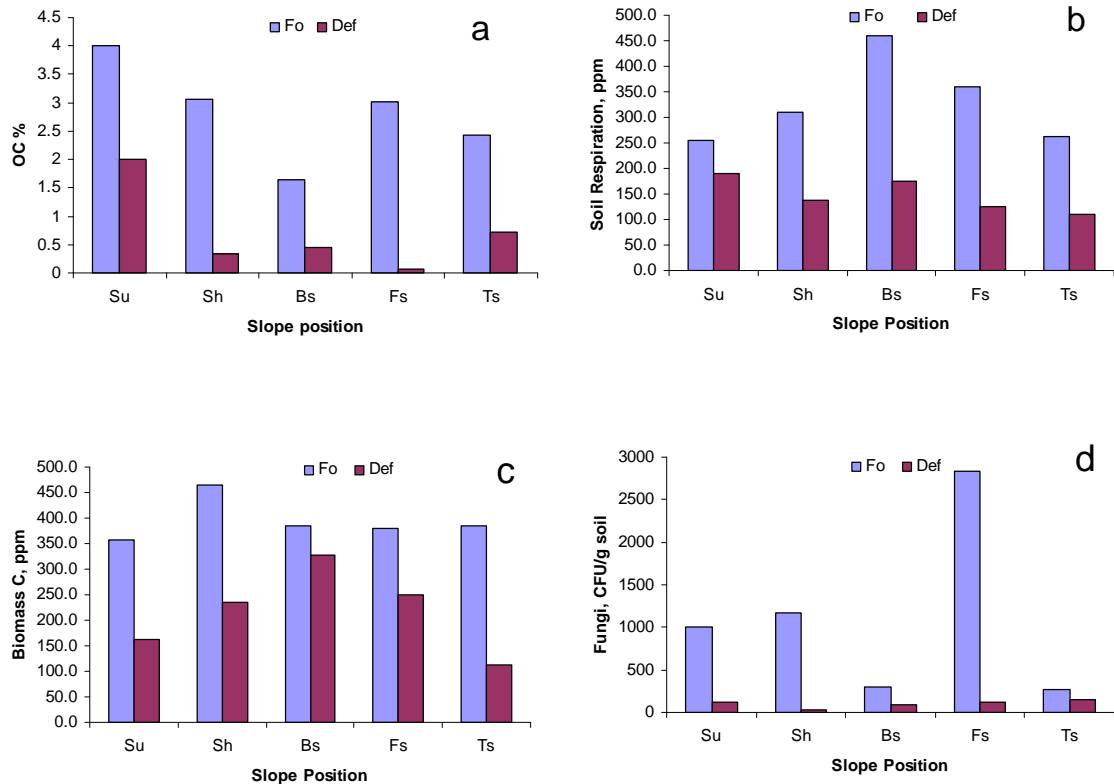
Farhad Khomali, SP Wani and Ch. Srinivasarao

### 3. Influence of Deforestation and Slope Position on C and N Stocks of the Losses Derived Hillslopes of Golestan Province, Iran

Conversion of natural forests to agriculture in Golestan Province of Iran is of great concern and a main cause of annual destructive flooding. The aim of this study was to determine the effect of deforestation and cultivation on the C and N pools in loess hillslopes.

The study area, Agh-Su is a part of the Gorganrood watershed located adjacent to Kalaleh city in eastern Golestan Province, northern Iran. The annual average soil temperature and the mean annual precipitation are 16 °C and 600 mm, respectively. The major parts of the study area are occupied by mountains and hills with the parent materials mainly composed of loess deposits, with a history of deforestation going back almost 50 years. Five pedons from different geomorphic units of a hillslope: summit (SU), shoulder (SH), backslope (BS), footslope (FS) and toeslope (TS) were sampled by horizon from forested and adjacent deforested cultivated land. Some physico-chemical analyses such as soil texture, bulk density, pH, EC, SP, CaCO<sub>3</sub>, available P and K were carried out with standard techniques. Organic, inorganic and total carbon was measured by TOC analyzer. Total N was analyzed using TNS equipment of the soil chemistry lab. Inorganic N, soil respiration, microbial biomass C and N, net N mineralization and population of bacteria, actinomycetes and fungi were determined in ICRISAT, India.

The soils of the forest land use were mainly classified as Alfisols in most of the slope positions. The adjacent deforested and cultivated land use however, lacked the requirement to be classified either as Alfisols or Mollisols, which was mainly related to soil erosion. Figures 9.1.2.10.2a to Figure 9.1.2.10.2d show the variation of some of the studied factors. SOC is significantly higher in all the slope positions of the forest compared to the cultivated land use. Similar results were also found for the soil respiration (b), biomass C (c) population of fungi (d), biomass N, total N, and mineralized N. Inorganic C (IC) is almost absent in all the different slope positions of forest indicating its favorable conditions for higher water infiltration and the downward leaching of carbonates.



**Figure 9.1.2.10.2 Variation in a) OC, b) soil respiration, c) biomass C and d) population of fungi in the forested (fo) and deforested (Def) land uses for different slope positions: summit (SU), shoulder (SH), backslope (BS), footslope (FS) and toeslope (TS)**

As can be seen in Figure 9.1.2.10.2 SOC and N pools have been significantly depleted by deforestation, which was largely due to the soil erosion of the highly susceptible loess derived soils. The higher amount of respiration observed in pedons taken from the forested slopes may be due to annual additions of new organic matter to soil surface. Loss of organic matter in the cultivated area as a result of tillage practices and inappropriate management have caused low respiration.

Loss of organic matter in this sloping cultivated areas resulted in sheet and rill erosion, especially in shoulder and backslope positions. For each slope, in both surface and subsurface layers of cultivated land use, the amount of IC was significantly higher than the forest soil. Population of fungi was highly influenced by deforestation, as soil pH was observed to increase following deforestation and tillage. Tillage is mainly responsible for uplifting of lime from lower calcic horizons. In contrast, populations of bacteria and actinomycetes were not significantly affected by deforestation.

The present investigation showed that clear-cutting and subsequent cultivation, particularly on loess derived hillslopes could cause significant degradation of soil quality attributes. Higher soil erosion, decrease in the stability of landscape, poor soil fertility, and finally, natural disasters such as flooding, land slide, soil creep and loss of life are the consequences of deforestation in the study area.

#### 4. Carbon Sequestration and Microbial Properties of Soils Under Different Rainfed Production Systems of India

Microorganisms play a critical role in nutrient transformation, soil health and for sustaining the productivity of soils. Effects of long-term cropping, fertilization, manuring and their integration on microbial community were studied in soil samples from five long-term fertilizer experiments under various rainfed production systems in the semi-arid tropics (SAT) of India. Microbial population counts were analyzed by dilution plating and were in turn compared with different parameters such as soil treatments, soil type, soil microbial biomass C, soil organic C, rainfall and soil pH. The counts were high in treatments where combinations of organic and inorganic fertilizers were applied than in control. Vertisols showed larger organic carbon levels than Alfisols. Fungal population was higher in acidic soils and in treatments under continuous inorganic fertilization treatments whereas a high number of bacteria were found in integrated use of organic and inorganic fertilizers. At most of the locations, Organic C and microbial biomass C showed significant positive ( $p \leq 0.05$ ) correlation with microbial populations. Thus, results suggest that even under arid and semi-arid tropical conditions, regular addition of nutrients in an integrated manner could improve soil organic carbon and microbial population counts. For each production system, better carbon sequestered management practices were identified.

**Table 9.1.2.10.1. Microbial parameters of Alfisol soil as affected by long-term (16 years under groundnut) fertility management at Anantapur**

| Treatment                                                                                                                             | Soil Biomass C<br>g Cg <sup>-1</sup> soil | Soil organic carbon g C<br>kg <sup>-1</sup> soil | Bacteria<br>(Log <sub>10</sub> ) | Fungi<br>(Log <sub>10</sub> ) | Actinomycetes<br>(Log <sub>10</sub> ) | Total of microbial population<br>(Log <sub>10</sub> ) |
|---------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|--------------------------------------------------|----------------------------------|-------------------------------|---------------------------------------|-------------------------------------------------------|
| Control (T1)                                                                                                                          | 115 <sup>±a</sup><br>(±7.8)               | 3.0 <sup>a</sup><br>(±0.45)                      | 4.78 <sup>a</sup><br>(±0.07)     | 3.11 <sup>a</sup><br>(±0.66)  | 3.40 <sup>a</sup><br>(±0.03)          | 4.80                                                  |
| 20–40–40 kg N, P <sub>2</sub> O <sub>5</sub> ,<br>K <sub>2</sub> O ha <sup>-1</sup> (T2)                                              | 144 <sup>±a</sup><br>(±7.3)               | 3.9 <sup>ab</sup><br>(±0.15)                     | 5.11 <sup>b</sup><br>(±0.10)     | 3.38 <sup>a</sup><br>(±0.11)  | 4.40 <sup>c</sup><br>(±0.03)          | 5.18                                                  |
| 10–20–20 kg N, P <sub>2</sub> O <sub>5</sub> ,<br>K <sub>2</sub> O ha <sup>-1</sup> (T3)                                              | 118 <sup>±a</sup><br>(±2.5)               | 3.4 <sup>b</sup><br>(±1.43)                      | 5.11 <sup>b</sup><br>(±0.07)     | 3.28 <sup>a</sup><br>(±0.07)  | 3.70 <sup>b</sup><br>(±0.06)          | 5.11                                                  |
| Groundnut shells @ 4 t<br>ha <sup>-1</sup> (T4)                                                                                       | 138 <sup>a</sup><br>(±27.8)               | 4.7 <sup>bc</sup><br>(±1.15)                     | 5.28 <sup>c</sup><br>(±0.02)     | 3.43 <sup>a</sup><br>(±0.05)  | 4.51 <sup>d</sup><br>(±0.07)          | 5.34                                                  |
| FYM @ 4 t ha <sup>-1</sup> (T5)                                                                                                       | 138 <sup>a</sup><br>(±26.2)               | 6.3 <sup>d</sup><br>(±1.85)                      | 5.71 <sup>d</sup><br>(±0.05)     | 3.46 <sup>a</sup><br>(±0.05)  | 4.48 <sup>cd</sup><br>(±0.04)         | 5.73                                                  |
| 10–20–20 kg N, P <sub>2</sub> O <sub>5</sub> ,<br>K <sub>2</sub> O ha <sup>-1</sup> + Groundnut<br>shells @ 4 t ha <sup>-1</sup> (T6) | 150 <sup>a</sup><br>(±7.1)                | 4.9 <sup>c</sup><br>(±1.0)                       | 5.43 <sup>d</sup><br>(±0.05)     | 3.46 <sup>a</sup><br>(±0.06)  | 4.54 <sup>d</sup><br>(±0.09)          | 5.48                                                  |
| 10-20-20 kg N, P <sub>2</sub> O <sub>5</sub> , K <sub>2</sub> O<br>ha <sup>-1</sup> + FYM @ 4 t ha <sup>-1</sup><br>(T7)              | 145 <sup>a</sup><br>(±5.5)                | 6.4 <sup>d</sup><br>(±1.8)                       | 5.76 <sup>e</sup><br>(±0.03)     | 4.34 <sup>b</sup><br>(±0.08)  | 4.45 <sup>cd</sup><br>(±0.06)         | 5.80                                                  |
| LSD (5%)                                                                                                                              | NS                                        | 1.4                                              | 0.12                             | 0.43                          | 0.09                                  | -                                                     |

Significant ( $p \leq 0.05$ )

Different letters in the same line indicate significant difference (at 5%) according to the Tukey test

C Vineela, S P Wani, Ch. Srinivasarao and KPR Vittal

#### Activity 9.1.2.11. Smallholder Adoption and Adaptation of Natural Resource Management Interventions in the Semi-Arid Rainfed Systems: Market, Policy and Institutional Lessons and Experiences – Bekele Shiferaw

This study has begun to review African and Asian experiences in promoting soil and water conservation and sustainable land management technologies. It synthesizes lessons from various case studies and offers new insights on approaches and strategies that accelerate widespread adoption and adaptation of such interventions.

The allied study also investigates the institutional and policy issues that limit effective participation of people in community watershed programs and identifies key determinants for the degree of CA and its effectiveness in achieving economic and environmental outcomes. Based on review of experiences and the empirical evidence in implementing Integrated Water Management programs especially in India, the study offers some new insights on future strategies for strengthening institutions for collective action to enhance the poverty and environmental impacts of watershed programs in India.

### **Major findings**

Review of the wide literature shows that resource poor farmers, especially in marginal and rainfed regions, continue to face complex challenges in adopting and adapting alternative management practices and innovations for mitigating this problem. In an effort to address this challenge, the approach to soil and water conservation itself has evolved over several phases; latest perspectives encouraging the need to ensure farmer participation and consideration of market, policy and institutional factors that shape farmers' incentives. The need for farmer participation and innovation is justified by the fact that most soil and water management problems tend to be site and even farm specific. This calls for the need to provide farmers with a set of options to fit specific niches depending on specific constraints rather than a wholesome "one-size-fits-all" type approach that promotes a single technological package in all areas.

The review also indicates that adoption and adaptation of land and water management innovations is constrained by failure to link conservation with livelihoods, extreme poverty and imperfect factor markets, inadequate property rights systems, and weak organizational and institutional arrangements at different levels. The best way to ensure adoption of innovations for sustainable land and water management is to develop them iteratively, in collaboration with the target group. This can be done through linking formal research with indigenous innovation processes of local resource users and communities. Effective soil and water conservation interventions are characterized by a process of joint innovation that ensures farmer experimentation and adaptation of new technologies and management practices and careful consideration of market, policy and institutional factors that condition and shape farmer conservation decisions.

Linking farmers to better markets for their produce and inputs like fertilizer and credit generally makes a positive contribution in raising the returns to land and labor in agriculture. When complimented with proper policies and institutional mechanisms to induce the process of farmer innovation and adoption of conservation practices, market access can be a useful driving force towards sustainable intensification of smallholder agriculture in both rainfed and irrigated areas. Given that investment poverty and lack of farmer capacity can be major limiting factors for certain sustainability-enhancing investments, access to investment credit at farmer affordable rates and availability of pro-poor options for beneficial conservation (ie, offer short-term livelihood benefits) will be an important step in solving some of the long-standing constraints.

In addition, experience has shown that projects should act as 'toolboxes', giving essential support to resource users to devise complementary solutions based on available options, rather than imposing exogenous practices and technologies. If investments in the resource provide a worthwhile return and when enabling policy and institutional arrangements empower individual resource users and communities, smallholder farmers often try to protect their land and water resources from degradation. The major challenges for future land and water management will be in addressing the externalities and institutional failures that prevent joint investments for management of agricultural landscapes and watersheds. This will require new kinds of institutional mechanisms for empowering communities through local collective action that would ensure broad participation and equitable distributions of the gains from joint conservation investments.

Finally, some of the key lessons for the future include:

- Future land and water conservation projects should be flexible enough to respond to land users' innovations and inputs;

- Land and water conservation interventions should favor approaches that provide a number of different technologies and management practices, which individual resource users can choose, test, adapt and adopt or discard as they see fit;

- Resource-poor farmers are unlikely to adopt interventions that do not provide short-term economic gains, especially when credit markets and property rights are imperfect to permit investments with long payback periods;

- Adoption requires a conducive institutional and policy environment and good linkages with product and factor markets to enhance the returns to beneficial conservation investments; and

Integrated and landscape-wide interventions require community participation and collective action to coordinate and regulate resource use and investment decisions.

The results of this work have been presented/published in:

**Dar DW and Twomlow SJ.** 2007. Managing agricultural intensification: The role of International research. *Crop Protection* 26: 399-407.

**Nkonya E, Shiferaw B and Msangi S.** 2007. Food security in the drylands of south Asia and sub-Saharan Africa: research challenges and opportunities. *Annals of Arid Zone* (Invited journal article for a special issue on Alternate Landuse Systems).

**Rusike J, Twomlow S, and Varadachary A** 2007. Impact of Farmer Field Schools on Adoption of Soil Water and Nutrient Management Technologies in Dry Areas of Zimbabwe. *In Land and Water Management for Sustainable Agriculture* (Mapiki A and Nhira C, eds.). Proceedings of the EU/SADC Land and Water Management Applied Research and Training Programme's Inaugural Scientific Symposium, Malawi Institute Management, Lilongwe, Malawi, 14 – 16 February 2006. Paper 6.3.

**Reddy VR, Shiferaw B, Bantilan C, Wani S and Sreedevi TK.** 2007. Collective Action for Integrated Watershed Management in Semi-Arid India: Strategic Policy and Institutional Options. Policy Brief No. 11. ICRISAT, Patancheru, India.

**Shiferaw B and Okello J.** 2008. Stimulating Smallholder Investments in Sustainable Land Management: Overcoming Market, Policy and Institutional Challenges. *In Determinants of Investments in Sustainable Agriculture in East Africa* (Bluffstone R and Kohlin G, eds.). Resources for the Future Press (Forthcoming)

Shiferaw B, Okello J and Reddy VR. 2008. Adoption and Adaptation of Natural Resource Management Innovations in Smallholder Agriculture: Reflections on Key Lessons and Best Practices. *Environment, Development and Sustainability* (forthcoming)

**Shiferaw B, Okello J and Reddy VR.** 2008. Challenges of Adoption and Adaptation of Land and Water Management Options in Smallholder Agriculture: Synthesis of Lessons and Experiences. *In Assessment of Agricultural Water Management in Arid and Semi-Arid Farming Systems* (Wani SP, Rockstrom J and Oweis T, eds.). CABI Publishing (Forthcoming)

**Shiferaw B, Reddy VR and Wani S.** Watershed Externalities, Shifting Cropping Patterns and Groundwater Depletion in Indian Semi-Arid Villages: The Effect of Alternative Water Pricing Policies. *Ecological Economics* (Under 2<sup>nd</sup> review).

**Shiferaw B, Tewodros A Kebede and Ratna Reddy V.** 2007. Community Watershed Management in Semi-Arid India: The State of Collective Action and its Effects on Natural Resources and Rural Livelihoods. Paper presented at the CAPRI Policy Conference, February 28 – March 2, 2007. Entebbe, Uganda.

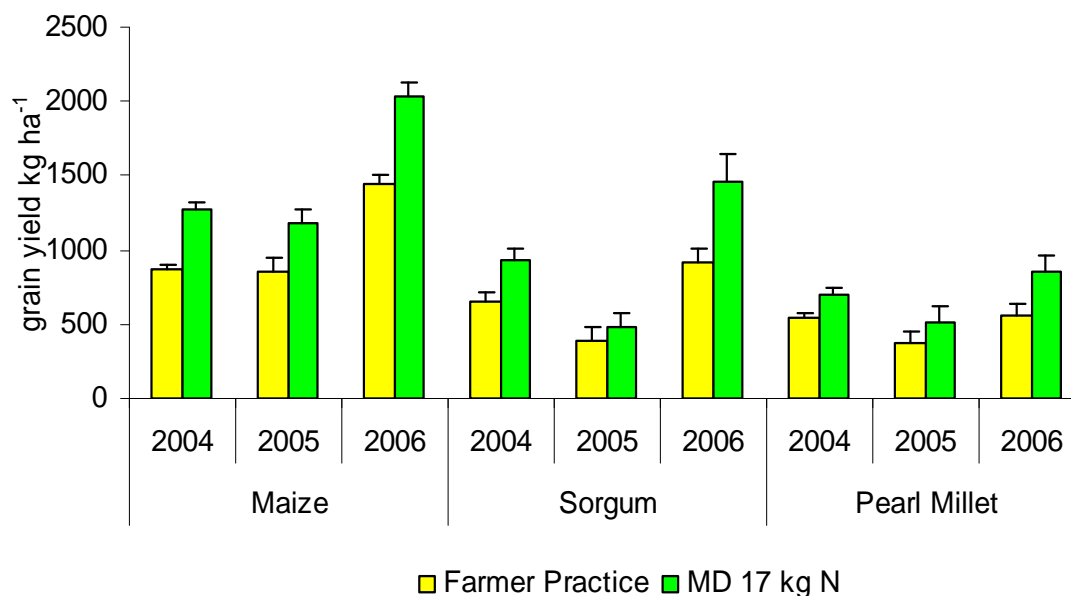
**Twomlow S, Shiferaw B, Cooper P and Keatinge JDH.** 2008. Integrating genetics and natural resource management for technology targeting and greater impact of agricultural research in the semi-arid tropics. *Experimental Agriculture* (forthcoming).

**Output 9.2. Affordable and sustainable crop management options (nutrients, water management, crop-livestock, IPM, cultivar, rotations) developed and promoted with associated capacity building in collaboration with NARES partners in Africa and Asia**

*Output Targets 2007*

*9.2.1 Precision application of low doses of N or P fertilizer on their own, or in combination with manure, widely disseminated in WCA and ESA regions*



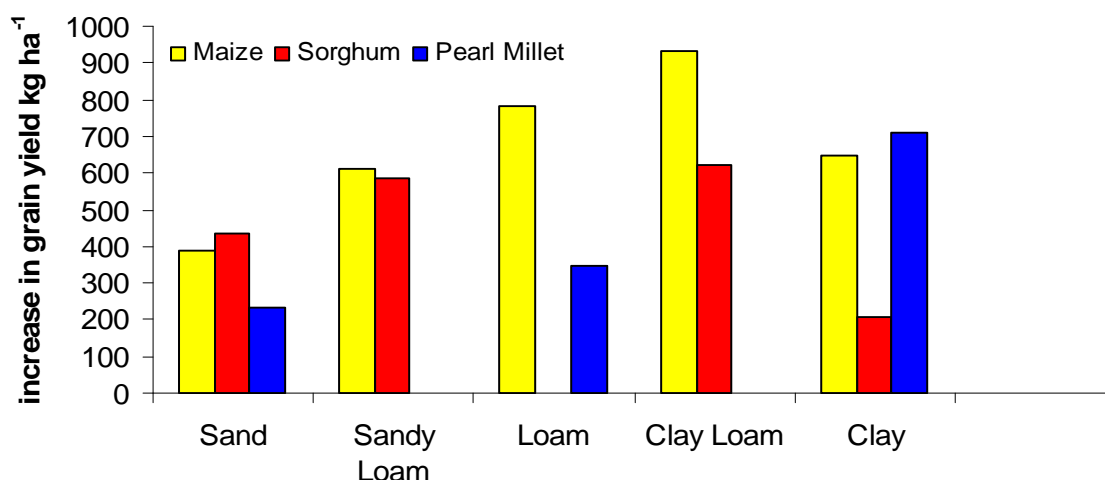


**Figure 9.2.1.1.1 Grain responses of cereals to a targeted application of 50 kg of Ammonium Nitrate Fertilizer (17 kg N ha<sup>-1</sup>) under farmer management. Mean of results across multiple sites for 2003/2004, 2004/2005 and 2005/2006 cropping seasons. Error bars represent standard errors of differences between the predicted means of the micro-dosing by crop yields**

**Activity 9.2.1.1 Micro-dosing as a Pathway to Africa’s Green Revolution: Evidence from participatory on-farm trials in Zimbabwe**

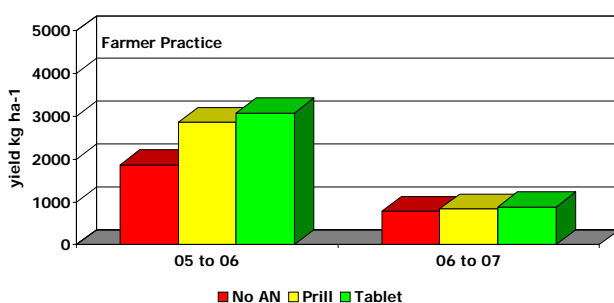
ICRISAT Zimbabwe has been working for the last ten years to encourage small-scale farmers to increase inorganic fertilizer use, and progressively increase their investments in agriculture, as the first steps towards Africa’s own Green Revolution. The program of work is founded on a technology breakthrough proven to be successful in a sub-set of communities in Southern Africa – micro-dosing using small targeted quantities of inorganic nitrogen fertilizer. It starts from the proposition that resource constraints prevent most risk averse farmers from pursuing rates of fertilizer application recommended by most national extension agencies. Rather than asking how can a smallholder subsistence farmer maximize her yields or profits, microdosing asks how can a farmer maximize the returns to a small initial investment – that might grow over time, turning deficits into surpluses.

Our results from three years of wide scale testing across southern Zimbabwe have consistently shown that fertilizer micro-dosing can, irrespective of the resource status of the household, increase grain yields by 30 to 50% in both low and high potential areas where farmers cannot afford to purchase the current recommended rates of fertilizer (Figure 9.2.1.1.1). This innovative technology involves the precision application of small quantities of Nitrogen-based fertilizer, close to the crop plant. This enhances fertilizer use efficiency (Figure 9.2.1.1.2 and improves productivity, enabling intensification of agriculture and productivity gains from initially low levels, closing the yield gap between what farmers are currently achieving, and what is achieved on the research station. Gains are even larger when fertilizer is combined with animal manures, better weed control, and simple water management methods.

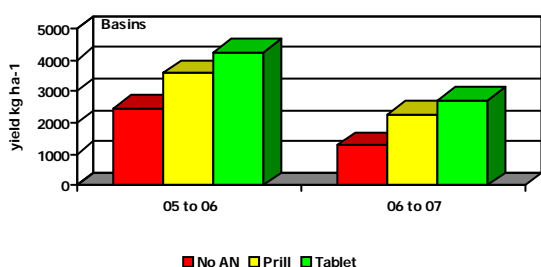


**Figure 9.2.1.1.2. Observed increases in cereal grain yield ( $\text{kg ha}^{-1}$ ) for 323 households from 13 districts across southern Zimbabwe in response to a targeted application of 50 kg of Ammonium Nitrate Fertilizer ( $17 \text{ kg N ha}^{-1}$ ) under farmer management for 5 different soil types in 2005-2006 season (between 15 and 45 kg of extra grain achieved for every kg of N applied).**

Although our microdosing work has shown consistent yield increases in excess of 30% (see Figure 9.2.1.1.), farmers have reported that it is time consuming, laborious and difficult to ensure each plant gets one third of a crown bottle cap. In an attempt to address these issues, a tablet of AN equivalent to the amount of fertilizer held in one third of a crown bottle cap has been developed. Laboratory tests showed that the tablets took four times longer to dissolve than conventional prill. Two seasons of testing of the tablets clearly shows the positive yield increases that can be achieved – particularly when we include a conservation farming practice such as planting Basins (Figure 9.2.1.3). The results have been so impressive that a venture capital company has approached ICRISAT and its Partner ‘Agri Seed Services’ to establish a company and commercialize the manufacture and sale of the tablets. This initiative is still under negotiation, as is further field and laboratory work to understand how the tableting changes the behaviour of the ammonium nitrate.



- 70 % yield reduction between seasons for farmer practice
- AN tablets produced 4% more grain yield than the prill formulation



- 40% yield reduction between seasons for Basins
- Top dressing increased grain yields in basins by at least 35%
- AN tablets produced 18% more grain yield than the prill formulation

**Figure 9.2.1.3. The effect of applying small doses of prill and tablet AN formulations on maize grain yield response under Farmer Practice and Basin Conservation Farming Systems in Masvingo District, Zimbabwe in the above average rainfall season of 2005/06**

Where do we go from here?

The microdosing success and experiences from southern Africa have been shared with CRS in Kenya. Although small packs of fertilizers are not a panacea for increasing access and utilization of fertilizer, it is definitely one of the options. This is particularly so for first users of fertilizers as well as those who are financially disadvantaged—making them unable to access the 50 kg bag of fertilizer. Those who are not intending to do large farming and require only minimal amounts such as small gardening would also opt for small packs. Last but not least micro-dosing practitioners would, on an average, prefer small packs because they may be needing less than a 50kg bag.

This work is having some serious policy implications within the regional fertilizer industry in terms of marketing policies for smallholder farmers – packaging, and is raising the interest of financial institutions in south Africa – both banks and insurance companies are being encouraged to explore new ways of increasing their support to the emerging smallholder sector. ICRISAT will have a major role to play in the coming years.

Steve Twomlow, John Dimes and Lewis Hove

**Activity 9.2.1.2 Improved fertilizer recommendations and policy for dry regions of southern Africa.**

An ACIAR funded project, “Improved fertilizer recommendations and policy for dry regions of southern Africa”, was conducted in Limpopo Province of South Africa in collaboration with the Limpopo Department of Agriculture (LPDA), the Limpopo Agricultural Strategic Team (LIMPAST), the Agricultural Research Council (ARC) and the Limpopo Community Development Program (LCDP). The project sought to increase use of inorganic fertiliser by smallholder farmers in Limpopo through (i) improved fertiliser recommendations more suited to their resource base and climatic risk and (ii) improved access to fertiliser through public-private partnership. The project has been conducted with a range of private-sector partners, including Progress Milling, a large private-sector grain milling and trading firm (and which sponsors LCDP); Sasol Nitro, a fertilizer manufacturer; Panaar, a seed company, and LIMPAST, a farmer development organization.

The project was initiated in July 2003 and an Extension phase is due for completion in September 2007. The project has built on previous ICRISAT work in Zimbabwe and Malawi testing small doses of N fertilizer as an option for farmers in dry areas. It complements the scaling out of this technology in Zimbabwe under the DFID funded Relief and Recovery Program.

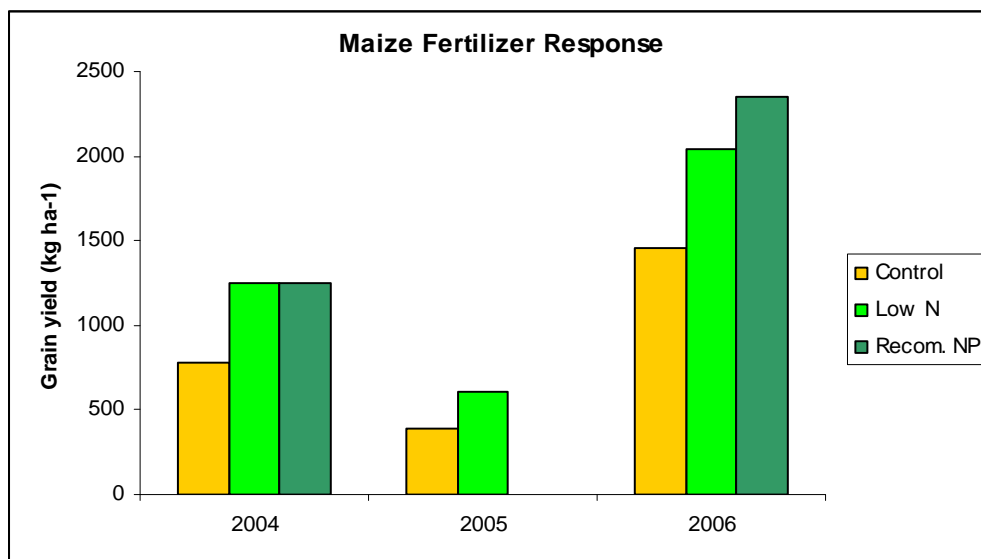
**Materials and Methods**

On-farm participatory trials were conducted in conjunction with LPDA and LIMPAST extension officers in Capricorn, Vhembe and Mopani districts of Limpopo Province in the 2003/04, 2004/05 and 2006/07 cropping seasons. The rainfall was about average (450mm) in the first season, below average in the second and above average for the final season, although in the early stages it was quite dry. On-farm trials were farmer-managed (planting date, weeding and date of top-dress). The project provided farmers with seed and fertilizer and instruction pamphlets on “how to apply small doses of N to maize”. The pamphlets were translated into Venda, N. Sotho, and Tsonga. In some cases, farmers were assisted in planting trials to demonstrate planting in rows, spacing of seed and basal application of fertilizer. Otherwise, farmers generally broadcast seed and plant with the passing of a tractor-drawn plough. At top-dress, on-farm trials were used to demonstrate application methods to farmer group members and extension officers.

In each season, farmer practice (no Top-dress) was compared with a small dose of N fertilizer (14 kg N ha<sup>-2</sup>) applied as top-dress. In 2003/04 and 2005/06, treatment plots with higher recommended applications of N and P were included. Treatment plot sizes varied between 100 and 200 m<sup>2</sup>. The project team and farmers jointly harvested trials. Plant growth data (plant and cob count, stover and grain yield) was sampled from an average area of 22.5 m<sup>2</sup>.

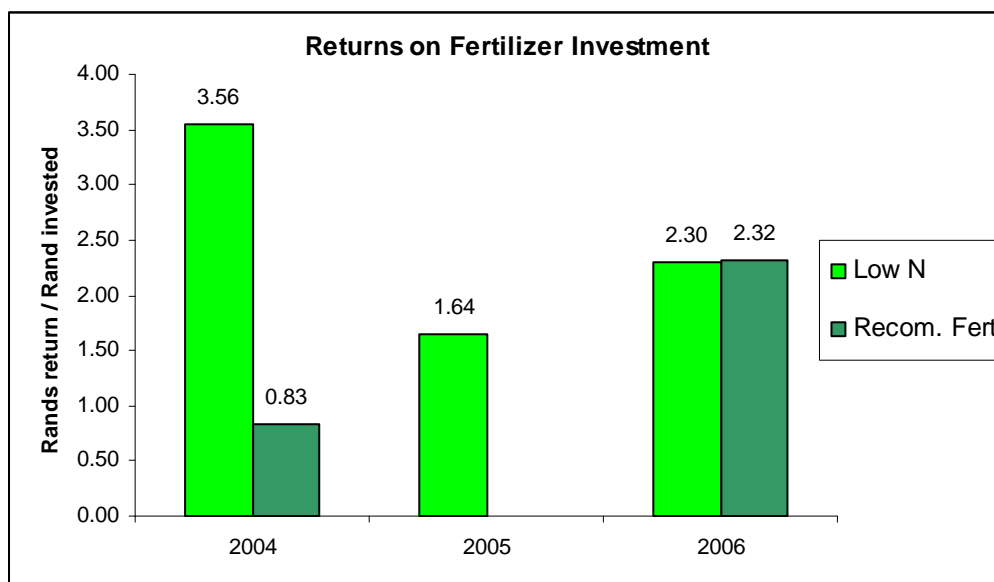
**Results**

The observed maximum maize grain yield varied with the seasonal rainfalls (Figure 9.2.1.2.1). However, irrespective of seasonal rainfall, there was a yield response to low doses of N as top-dress. In 2006, a yield response to higher N (and P) input was evident, but this was not the case in 2004. The small dose of top-dress N increased grain yield by more than 50% across years compared to current farmer practice.



**Figure 9.2.1.2.1. Maize grain yield response to fertilizer investments in on-farm trials conducted across 3 growing seasons in Limpopo Province, RSA.**

Analysis of the value cost ratio (VCR) for low and recommended doses are shown in Figure 9.2.1.2.2. VCR is calculated from the value of extra grain produced relative to the control and the cost of the additional input(s). In 2004 and 2006, the VCR for low N exceeds the 2:1 threshold commonly thought necessary to encourage risk-averse farmers to invest in a new technology. The Recommended treatment exceeds the threshold in 2006 (wet year) but falls substantially below it in 2004, an average rainfall season. Most importantly, in 2005, the VCR for the low N dose was 1.64, meaning a farmer would still get a return substantially exceeding the amount invested.



**Figure 9.2.1.2.2. The Value Cost Ratio of maize grain yield response to fertilizer investments in on-farm trials conducted in Limpopo Province, RSA.**

### Simulation analysis

The field trials were supported with crop simulation analysis to ascertain the spatial variability of the expected N response with rainfall climate. Long term climate data (21 to 30 years) from six sites across the Limpopo Province were used to analyse fertilizer N response for a typical shallow sandy soil with low soil organic carbon content (0.6% OC). The fertilizer treatments included a control (0N), farmer current practice (1 bag of Starter = 3 kgN ha<sup>-1</sup>), a common increment in farmer practice, namely 2 bags of Starter (they find this convenient, 6kgN

ha<sup>-1</sup>), an investment in topdress N fertilizer (14 kgN ha<sup>-1</sup>), a balanced nutrition option ( 1 bag Starter + 1 bag Topdress = 17 kgN ha<sup>-1</sup>), and the current extension recommendation for the province (4 bags Starter + 2 bags Topdress = 40 kgN ha<sup>-1</sup>). While these treatments included additions of P, K and some lime (LAN is the topdress fertilizer), the APSIM maize model used in the analysis responded to N inputs only.

### Results

The average in-crop rainfall (for a sowing window of 1 December to 10 January) for the six sites ranged from 194mm to 590mm. For the control treatment (0N), the average simulated maize grain yield for the six sites ranged from 288 kg ha<sup>-1</sup> to 540 kg ha<sup>-1</sup>. This shows that, in the absence of N inputs, maize yields responded only marginally to the almost 3 fold increase in rainfall.

Figure 9.2.1.2.3 shows the large differences in expected maize response to levels of N fertilizer across the 6 sites. Two features of the graph are significant. Firstly, the expected maize yield for the current Extension recommendation of 40 kg N ha<sup>-1</sup> ranges from as little as 470 kg grain ha<sup>-1</sup> at the driest site, to 1750 kg ha<sup>-1</sup> at the wettest site. Clearly, the current blanket recommendation needs to be broadened to account for agro-ecological conditions. Secondly, except for the driest site, the fertilizer response is almost linear up to the 14kg N ha<sup>-1</sup> application rate. Hence the marginal return to N fertilizer, though different for the different rainfall climates (ie, the slope varies reflecting reliability in rainfall) is consistent at the low input levels. This suggests that resource-poor farmers can invest up to 14kgN ha<sup>-1</sup> without, on average, taking on any additional risk due to unreliable rainfall patterns. Hence, even in Levubu, the most favorable rainfall site, it makes sense to promote small doses of N fertilizer if a farmer has limited investment capacity.

For simulated output, the average VCR of N fertilizer investments was maximum for all sites at 14 kg N ha<sup>-1</sup>, ranging from 5.7:1 at Levubu, to 3.0:1 at Mara and only dropping below 2:1 at Macuville (Figure 9.2.1.2.4). The simulated VCRs are generally higher than the observed values in Figure 2, firstly due to the number of seasons sampled, but also because weed competition was not included in the analysis. Meanwhile, for the Extension Recommendation, the average VCR ranged from 1.7:1 to 0.3:1. However, as with the Starter fertilizer treatments (3 and 6 kgN ha<sup>-1</sup>) which generally had VCRs of around 1:1, this analysis ignores any crop response to the P and K contents in these fertilizers. While this is valid in the case of K (maize response to K in Limpopo Province is very rare), some project results have shown a clear response to P. Studies are currently under-way with Sasol Nitro and Limpopo University to evaluate APSIM performance for simulating maize NxP responses in the Province.

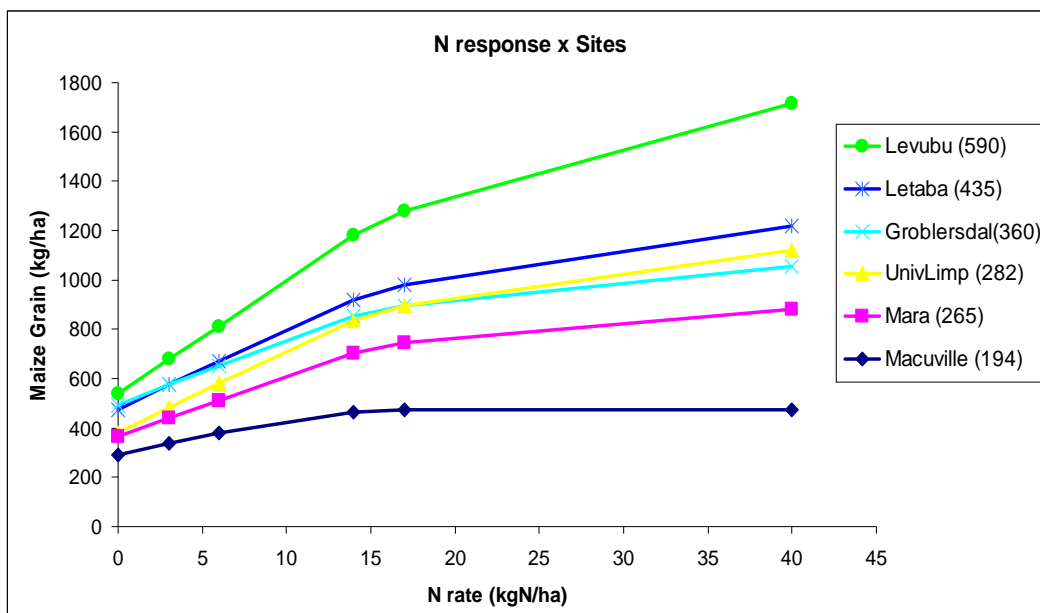
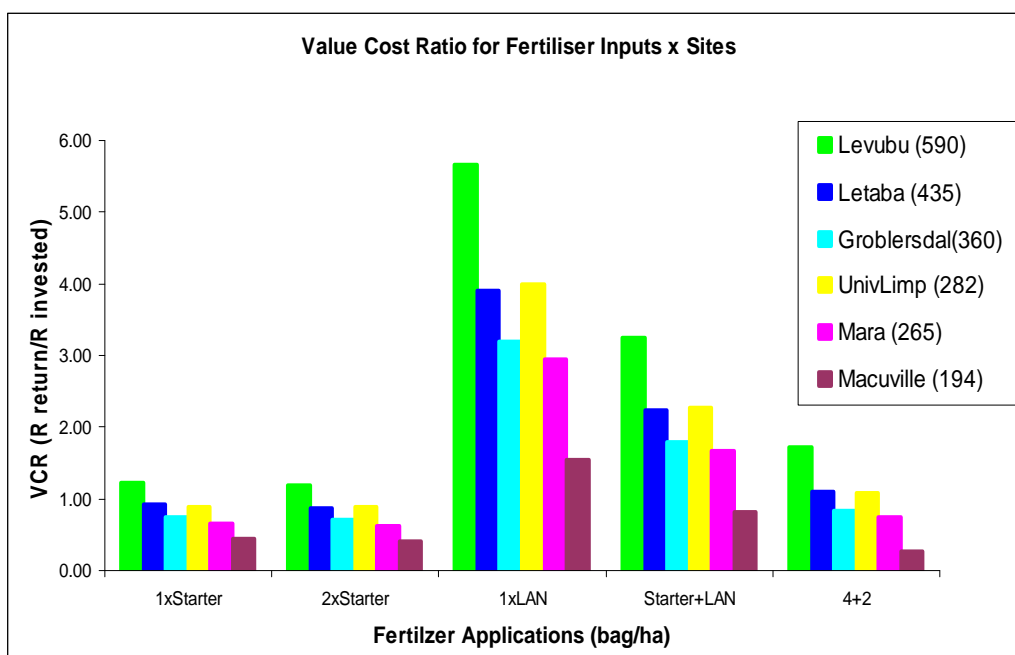


Figure 9.2.1.2.3. Simulated maize N response curves at 6 sites in Limpopo Province, RSA. (Numbers within parentheses in the sites legend is average in-crop rainfall.)



**Figure 9.2.1.2.4. Value Cost ratios for simulated maize response to fertilizer inputs at 6 sites in Limpopo Province, RSA.**

### Conclusion

The maize grain yield responses in Limpopo support evidence from Zimbabwe (Activity 9.2.1.1) that small doses of N can substantially increase yields relative to farmer practice, thereby contributing greatly to improved food security. Further, the economic analysis demonstrates that the low N technology is a less risky investment option in drought-prone regions compared with the current fertilizer recommendations, making it a more attractive option for resource-poor farmers. Because of the strong interaction crop N response has with rainfall, crop simulation modeling is an essential tool for fertility management studies in the SAT. In this case, it was able to demonstrate how a blanket fertilizer recommendation for the Limpopo Province is inappropriate, and provided supporting evidence to the low risk and high returns to be gleaned from investment in small doses of N in the Province, where soils of low organic matter are widespread.

John Dimes

### Activity 9.2.1.3 Public-Private Partnership improves fertilizer use in semi-arid agro-ecologies

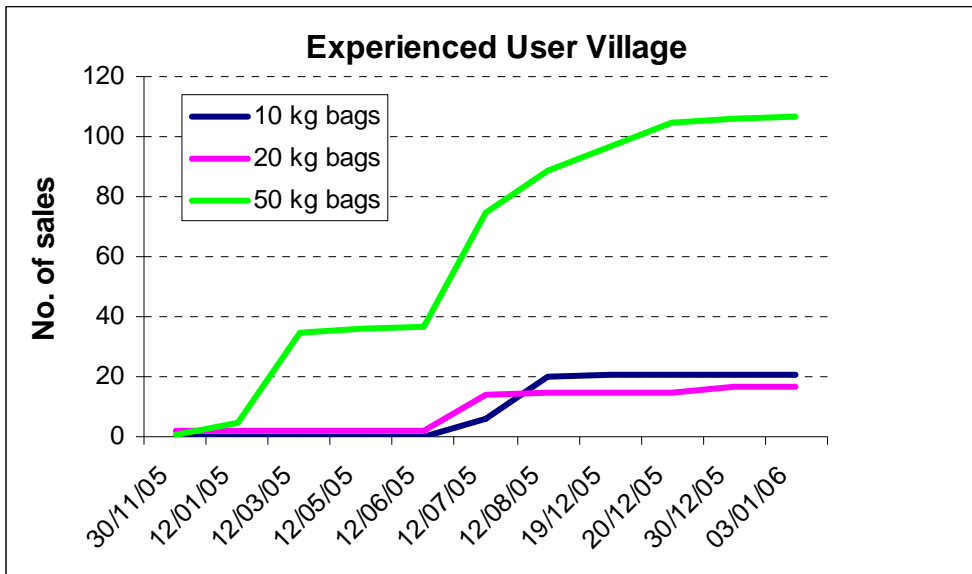
In 1997 Progress Milling (PM), the largest miller in Limpopo Province, RSA, established the Limpopo Community Development Program (LCDP) to help coordinate public and private investment aimed at increasing agricultural productivity and economic livelihoods of rural communities in the Province. It coincided with PM's investment in rural depots for sale of maize, and exchange and purchase of farmer's grains at community level. In 2003, ICRISAT joined LCDP and conducted research with a farmer organization (LIMPAST) and the Limpopo Department of Agriculture (LPDA) on testing low doses of fertilizer as an investment option for resource-poor farmers in drought prone regions. Up to this time, fertilizer had been sold in the PM depots in the traditional 50kg pack size and total sales for the previous 5 years were approximately 85 t.

To complement the fertilizer research, PM, LIMPAST and ICRISAT approached Sasol Nitro in 2004 to become a financial partner in LCDP, and to supply fertilizer for sale at PM depots. Sasol Nitro is a major fertilizer manufacturer and supply company in South Africa. In line with the philosophy of the small dose fertilizer option providing farmer's choice, ICRISAT proposed testing the sale of small (10 and 20 kg) pack sizes in addition to the traditional 50kg bags, as a more appropriate fertilizer marketing strategy for resource poor farmers. Sasol proceeded to register 10 and 20 kg packs of Starter and Top-dress fertilizer. In the 2005/06 and 2006/07 seasons, Sasol Nitro supplied PM with the 3 pack sizes of fertilizer for sale at depots. The Sasol agronomist also assisted in conducting demonstration trials with farmer groups associated with the PM depots. As a member of the LCDP, Pannar Seeds supported the marketing trial with small packs of OPV and hybrid maize and sorghum seed for sale at the depots.

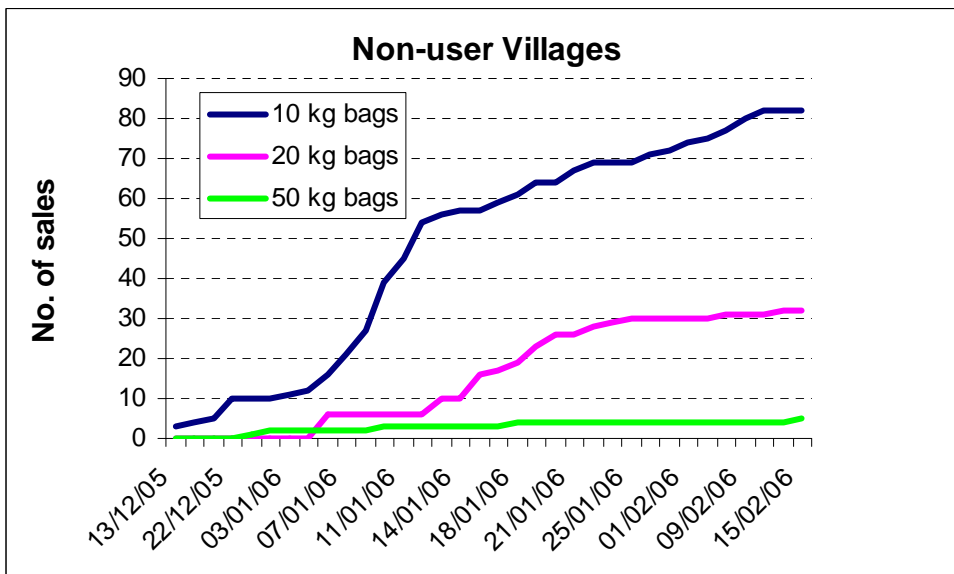
**Results**

Results show that in villages where farmers were familiar with fertilizer use, purchase of 50kg bags dominated sales (Figure 9.2.1.3.1). However, about 20% of sales were nevertheless in small packs. In villages where use of fertilizer was uncommon, 99% of sales were in small packs, and the daily record of sales show that 10kg packs were preferred to 20kg packs (Figure 9.2.1.3.2). Pannar also reported that 20 t of seed was sold at the depots, and that these sales were additional to normal sale volumes in the Province.

Sale of fertilizer through Progress Milling’s community-based depots in the last 2 seasons has yet to reach significant quantities, but the trends are all positive. From a base of 85 tons in total for the previous 5 years, this tonnage was exceeded by more than 10% in the first trial season of 2005/06. Of the total, 20% was sold in small pack sizes. In 2006/07, initial sales were affected by a general shortage of fertilizer in RSA and a very dry January to March period restricted demand for topdress fertiliser. Nevertheless, total fertilizer tonnage sales for the season increased by 45%, of which 22% was in small pack sizes. However, sale of fertilizer was adversely affected by logistical factors such as late supply and distribution to depots, re-stocking delays and distribution gaps (no supply to depots supported the previous season). Progress Milling, Sasol Nitro and Pannar Seeds have taken steps to overcome these constraints by jointly appointing a Development Coordinator in November 2006.



**Figure 9.2.1.3.1. Daily sales of fertilizer pack sizes at Progress Milling depots at Perskebult in Limpopo Province during 2005/06**



### **Figure 9.2.1.3.2. Daily sales of fertilizer pack sizes at Progress Milling depots at Motupa+Lenyene in Limpopo Province during a 2005/06**

#### **Conclusions**

The results provide supportive evidence for the hypothesis that small packs encourage farmer experimentation in fertilizer use and that it is a worthwhile marketing strategy for targeting increased fertilizer use by smallholder farmers, especially in drier areas. The increased sale of seed reported by Pannar also suggests that there is un-met demand even for improved seed, and that community based outlets will greatly help farmers access crop improvement technologies.

The results from Activities 9.2.1.1 to 9.2.1.3 have been presented in:

**Dimes J and Twomlow S.** 2007. The Role Of Modeling In The Development And Uptake Of Small Dose Fertilizer Technology In Southern Africa. Paper presented at Farming Systems Design 2007, September, 2007, Sicily.

**Ncube B, Dimes J, Twomlow S, Mupangwa W and Giller K.** 2007. Raising The Productivity Of Smallholder Farms Under Semi-Arid Conditions By Use Of Small Doses Of Manure And Nitrogen: A Case Of Participatory Research. *Nutrient Cycling in Agro-ecosystems* 77:53-67.

**NCUBE B, Twomlow S, Wijk M, Dimes J and Giller K..** 2007. Productivity and residual benefits of grain legumes to sorghum grown in rotation under semi-arid conditions in south-western Zimbabwe. *Plant and Soil* 299(1):1-15

**Twomlow S, Rohrbach D, Rusike J, Mupangwa W, Dimes J, NCUBEB, Hove L, Moyo M, MASHINGAIDZE N and MAPHOSA P.** 2007. Micro-dosing as a Pathway to Africa's Green Revolution. Evidence from participatory on-farm trials. Paper presented at the AFNET and SOFECSA International Symposium on Innovations as Key to the Green Revolution in Africa: Exploring the scientific facts. Arusha, Tanzania 17-21 September 2007.

**Twomlow S, Rohrbach D, Rusike J, Mupangwa W, Dimes J and NCUBE B.** 2007. Spreading The Word On Fertilizer In Zimbabwe. In: Mapiki A and C. Nhira (eds.) *Land and Water Management for Sustainable Agriculture. Proceedings of the EU/SADC Land and Water Management Applied Research and Training Programme's Inaugural Scientific Symposium, Malawi Institute Management, Lilongwe, Malawi, 14 – 16 February 2006.* Paper 6.21

John Dimes

#### **Activity 9.2.1.4 Toward farm specific recommendations for the use of mineral fertilizers in Sahelian crop-livestock systems.**

Low soil fertility is recognized as the major constraint to rainfed cereal production in the Sahel. Given that most farmers cannot afford enough fertilizer to cover all their fields, it is important to fine-tune the recommendations to maximize the fertilizer economic return at farm level while minimizing economic risks linked to climate fluctuations. This study was designed to help draw site/year/farm specific recommendations regarding hill placed application of mineral fertilizer either combined or not with organic amendments. A three year, multi-factorial experiment was conducted on-farm in three villages of one of the benchmark sites of the project from 2003 to 2005 to test the effect of hill-placed application of small doses of DAP fertilizers on three pearl millet (*Pennisetum glaucum* (L.) R. Br.) genotypes for a range of organic amendments.

Results showed a consistent grain yield increase due to fertilizer application for the no-manure plots on 2 sites, the fertility level of the third site being good enough to mask to the effect of mineral fertilizer with the exception of 2004, marked by an early drought. In normal conditions, no synergism was detected between organic and mineral fertilizer. However, it became apparent in the case of re-sowing or late sowing with a larger effect of mineral fertilizer on manure plots.

Overall, the year 2004 had higher yields than 2003. In 2005, yields were on average 241 kg ha<sup>-1</sup> lower than in 2003 which can be explained by a lower seasonal rainfall and dry spells during the first part of the season. There is a strong interaction between site and year, especially for Banizoubou in 2004 (reduction of 372 kg ha<sup>-1</sup> in grain yield) where sowing was delayed by 40 days after the onset of the rainy season due to labor constraints.



**Table 9.2.1.4.1: Grain yield response to mineral fertilizer per site/year/manure stratum. Standard error of difference (sed) was obtained by individual Anova (one analysis per site/year/stratum) for the 3 cultivars combined (9 repetitions at the fertilizer treatment level). Value cost ratio (VCR) is a monetary value of additional millet grain yield compared to control divided by the cost of fertilizer (millet grain price : 12,000 CFA/100 kg bag; DAP: 12,000 CFA/50 kg bag; Urea: 10,000 CFA/50 kg bag)**

| Site   | Year | Manure         | Control | DAP  | DAP + Urea | sed | VCR DAP | VCR DAP+U |
|--------|------|----------------|---------|------|------------|-----|---------|-----------|
| Bagoua | 2003 | No manure      | 427     | 439  | 406        | 60  | 0.30    | -0.37     |
|        |      | Transp. manure | 708     | 636  | 631        | 106 | -1.80   | -1.36     |
|        |      | Corralling     | 952     | 968  | 903        | 92  | 0.40    | -0.86     |
|        | 2004 | No manure      | 361     | 569  | 588        | 100 | 5.20    | 4.01      |
|        |      | Transp. manure | 692     | 862  | 712        | 67  | 4.25    | 0.35      |
|        |      | Corralling     | 1187    | 1153 | 1133       | 113 | -0.85   | -0.95     |
|        | 2005 | No manure      | 207     | 230  | 289        | 37  | 0.58    | 1.45      |
|        |      | Transp. manure | 384     | 379  | 375        | 44  | -0.13   | -0.16     |
|        |      | Corralling     | 592     | 493  | 566        | 55  | -2.48   | -0.46     |
| Bani   | 2003 | No manure      | 236     | 435  | 497        | 56  | 4.98    | 4.61      |
|        |      | Transp. manure | 668     | 689  | 697        | 90  | 0.53    | 0.51      |
|        |      | Corralling     | 1689    | 1288 | 1508       | 281 | -10.03  | -3.19     |
|        | 2004 | No manure      | 8       | 210  | 153        | 53  | 5.05    | 2.56      |
|        |      | Transp. manure | 505     | 913  | 874        | 129 | 10.20   | 6.51      |
|        |      | Corralling     | 787     | 975  | 1109       | 150 | 4.70    | 5.68      |
|        | 2005 | No manure      | 84      | 302  | 404        | 48  | 5.45    | 5.65      |
|        |      | Transp. manure | 466     | 465  | 521        | 84  | -0.03   | 0.97      |
|        |      | Corralling     | 322     | 469  | 557        | 54  | 3.68    | 4.15      |
| Kodey  | 2003 | No manure      | 72      | 232  | 241        | 42  | 4.00    | 2.98      |
|        |      | Transp. manure | 500     | 461  | 471        | 52  | -0.98   | -0.51     |
|        |      | Corralling     | 324     | 530  | 576        | 102 | 5.15    | 4.45      |
|        | 2004 | No manure      | 240     | 373  | 382        | 42  | 3.33    | 2.51      |
|        |      | Transp. manure | 676     | 740  | 755        | 100 | 1.60    | 1.39      |
|        |      | Corralling     | 831     | 741  | 871        | 73  | -2.25   | 0.71      |
|        | 2005 | No manure      | 85      | 220  | 198        | 19  | 3.38    | 1.99      |
|        |      | Transp. manure | 360     | 345  | 367        | 50  | -0.38   | 0.12      |
|        |      | Corralling     | 440     | 315  | 302        | 57  | -3.13   | -2.44     |

Large differences in grain yield and VCR can be observed between sites, years and manure strata (Table 9.2.1.4.1). For 2 of the 3 sites (Banizoumbou and Kodey), with low inherent soil fertility and overused soils, the best return to investment for the three years was for application of DAP on plots without manure application. For the Bagoua site, there was no clear response to DAP even on the plots that did not receive any manure, except for the year 2004. At this site, the use of small quantities of mineral fertilizer gave a positive VCR only in 2004, when non-manure and transported manure plots had to be re-sown after the failure of the first sowing. This suggests that such small doses of mineral fertilizer might be of very strategic use in productive fields when a sowing failure at the onset of the rainy season occurs. Similar trends were observed for Banizoumbou in 2004 due to the delayed sowing: for the DAP treatment, VCR ranged from 4.70 to 10 for the no manure, transported manure and corralled strata. N leaching with the advancing wetting front following rapid organic matter mineralization at the start of the rainy season can prevent young seedling from accessing that N in case of delayed sowing. Giving access to P through localized DAP application probably induced faster root growth, enabling the plant to catch-up with N in the soil profile.

Many Sahelian countries suffer from food security problems due in part to erratic rainfall but also to soil fertility decline. Strategies in terms of food security should not only focus on emergency food and seed aid but should also try to implement responsive fertilizer aid in zones where the onset of the rainy season has been delayed or

where crop failure has occurred because of early drought. If well implemented, the benefits for the countries could be very large: 20 kg of DAP can produce 200 kg of grain (a volume ratio of 1 to 10) which subsequently can save public money on food aid and large transport costs linked to it. This of course implies a need to revisit early warning systems to be able to identify vulnerable zones during the first third of the rainy season, and to have readily available strategic stocks of P fertilizer throughout the country.

This research was presented at the 16<sup>th</sup> International Symposium of the International Scientific Centre for Fertilizers (CIEC). 16-19 September 2007. Ghent, Belgium by B Gérard, BD Fatondji, C Dandois, C Manayame and C Biolders.

Bruno Gerard and the DGDC Improved Livelihoods in Sahel through the development and implementation of households bio-economics decision support systems project.

#### **Activity 9.2.1.5. Effect of sowing date on development and yield of seven Sahelian millet genotypes under non-limiting water and nutrients supply: experiment and simulation with APSIM**

In the Sahel, farmers usually sow after the first substantial rainfall event, despite a high risk of sowing failure due to the highly erratic rainfall pattern at the onset of the rainy season. This behavior has been explained by two assumptions. Firstly early sowing benefits from the nitrogen flush associated with the rapid mineralization of organic matter upon first wetting after a long dry season. Secondly, early sowing is associated with long day-lengths (photoperiods) and high air temperatures that are supposed to affect millet growth and production. In fact, photoperiods are long (13h12mn to 13h40mn) during the reasonable sowing period (April to July) and decrease significantly only after the end of July. Temperatures are also high in the sowing period and decrease afterwards with rainy season establishment. Under non-limiting water and nutrient supply, the effect of photoperiod and temperature are expected to dominate over the effect of N flush.

The objective of this research was to measure and simulate the effect of sowing date (associated with decreasing photoperiod and temperature) on millet phenology and yield for 7 common genotypes in Niger under non-limiting water and nutrients supply.

The experiment consisted in a completely randomized block design with two factors in three replications: (1) seven millet genotypes (Table 1) and (2) four sowing dates (S1 to S4) at one month interval (19 April, 19 May, 18 June and 19 July), covering the widest and reliable millet sowing period in the Sahel. Photoperiod at sowing were 13.17, 13.52, 13.69 and 13.58 hr for the first to the fourth sowing. Individual plot size was 9 x 11 m. A total of 60 kg N ha<sup>-1</sup>, 12 kg P ha<sup>-1</sup> and 9 kg K ha<sup>-1</sup> were applied combining a basal dressing of Single Superphosphate (SSP) before sowing, hill placed NPK (15-15-15) at sowing and split application of urea approximately at tillering and flowering. Millet was sown at a density of 10,000 hills ha<sup>-1</sup> and thinned to 3 plants per hill between 15 to 20 days after emergence. Millet cultivar used were selected from the most common landraces (Ankoutés, Hainikirey, Maewa and Zongo) and improved cultivars (ICMV-IS-89305, CIVT and ZATIB) from western and eastern Niger.

Only one studied cultivar, Maewa, was very photosensitive contrary to the other landraces and all the improved cultivars. It is well known that improved cultivars are generally early maturing, have stable crop duration due to intentionally reduced photosensitivity (Dingkuhn *et al.* 2006). Farmers make use of photosensitive and non-photosensitive cultivars which they sow according to farm distance to household and sowing dates. Improved cultivars mainly originated from non-photosensitive landraces. For instances, improved cultivar, used in this study (CIVT, ICMV-IS89305 and ZATIB) were derived from non-photosensitive landraces such as Hainikirey-Bengou HKB, Guerguera and Tamangagi among others.

The study showed that landraces produced more total leaf number (TLN), leaf area index (LAI) and straw yield whereas improved cultivar produced more grain yield except for cultivar Maewa. This difference in cultivar could be explained by the greater NPP and 1000 grain weight observed in improved cultivar and Maewa. Improved cultivars have a higher harvest index, because priority was given to grain production as opposed to other harvestable products. Stem, or green foliage have multiple uses in traditional systems (Dingkuhn *et al.* 2006) which explain farmers' attachment to landraces.

Late sowing resulted in decreased TLN, LAI, straw and grain yield and the number of grains per head was similar for sowing 1 and 2 but decreased significantly for sowing 3 and 4 respectively. Reddy and Visser (1993) also studied the photosensitive landrace Somno and the non-photosensitive HKB in Bengou, Niger on 6 sowing

dates during the 1986 and 1987 rainy seasons (no irrigation) following the application of  $45 \text{ N ha}^{-1} + 9 \text{ kg P ha}^{-1}$  and obtained similar results of adverse impact of late sowing on straw and grain yields, although Somno grain yield were more stable. Three hypotheses may explain the detrimental sowing date effect on the above millet growth variables: the nitrogen flush, temperature and temperature x photoperiod effects. Concerning the nitrogen flush, associated with first soil wetting and benefiting early sowing, the application of the  $60 \text{ kg N ha}^{-1}$  in this experiment can be considered as enough to mask this effect. Bationo et al. (1990) showed in Niger that at plant density of 15,000 to 20,000 hills  $\text{ha}^{-1}$  and N application of  $30 \text{ kg N ha}^{-1}$  in two splits achieved good yields in average and wet years, with only a small yield reduction in the drought year. Other works reported comparable decrease in agronomic variables with sowing date independently of N application rates. It was shown that when pearl millet cultivar MX001 was grown at a range of nitrogen supplies, the number of leaves initiated and the size of apical dome at panicle initiation did not vary with nitrogen supply (Coaldrake & Pearson 1985). Nitrogen supply affected the total leaf area of the main stem by affecting individual leaf size, not the number of leaves produced (Coaldrake 1985). The same authors concluded that daylength controlled the time to panicle initiation by determining the number of leaves which had to be initiated before PI could occur. In terms of temperature, Coaldrake and Pearson (1986) showed that temperature prior to PI determined the number of leaves initiated on the main stem and the size of the apical dome at the start of PI. This could support our result and may also affect NPP that mainly inferred on grain yield. The temperature prior to PI affecting the size of apical dome could also explain the difference in grain number (similar in S1 and S2 in contrast to S3 and S4). The average temperature after sowing was  $33.7 \pm 1.7$  and  $32.8 \pm 2.9$  for S1 and S2 compared to  $29.2 \pm 1.6$  and  $29.5 \pm 1.4$  for S3 and S4 (mean  $\pm$  SD) over the twenty DAS after which PI was probable. Moreover there is a difference between air and soil temperature and the meristem temperature before initiation is closer to the soil one (Ong 1983).

A journal article by PI Akponipke, B Gerard, F Dougbedji, B Clerget, E Van Oosterom and C Biolders is in preparation and will be submitted early 2008.

Bruno Gerard and the DGDC Improved Livelihoods in Sahel through the development and implementation of households bio-economics decision support systems project.

### **Activity 9.2.1.6 Promotion of Micro-dosing and Warrantage in West**

The fertilizer microdosing technology deals with the application of small quantities of fertilizers in the planting hole thereby increasing fertilizer use efficiency and yields while minimizing input cost. The combination of fertilizer microdosing with the complementary institutional and market linkages, through the Warrantage system offers an excellent option for improving crop productivity and increasing farmers' incomes in the semi-arid Sudano-Sahelian zone of West Africa. The Warrantage credit facility was initiated in Niger in the late 1990's to remove barriers to the adoption of soil fertility restoration inputs. ICRISAT is working closely with Projet Intrants FAO, several NGOs, national and international research organizations, development agencies, extension services and other stakeholders to help farmers develop and strengthen cooperatives. In the past few years, USAID assisted ICRISAT to complement FAO's efforts for demonstrating and promoting the fertilizer microdosing technology and the Warrantage system in Burkina Faso, Mali and Niger. Recently we won a competitive grant from the West and Central African Council for Agricultural Research and Development (CORAF/WECARD), with funds from the African Development Bank to pursue our efforts to disseminate the technology in West Africa. We are also exploring other sources of funding (ie, Bill and Melinda Gates Foundation, etc.) to scale-up and out this promising technology to millions of farmers across the West and Central African Region.

#### *On-farm trials and demonstrations*

Demonstrations and on-farm trials involving microdosing technology were conducted in Burkina Faso, Mali and Niger between 1998 and 2007. These field experiments were designed by the researchers but were managed by the farmers themselves with training and technical backstopping from extension agents, NGOs, and scientists. Experimental plots and types of fertilizers used varied between study sites depending on the local conditions and the availability of these inputs.

#### *On-farm field experiments*

These on-farm field tests included demonstration plots and Farmers Field Schools (FFS) using the fertilizer microdosing technology. The demonstration tests consisted of three plots per farmer, each plot measuring approximately 300 square metres ( $\text{m}^2$ ). Three treatments consisted of the farmers' practice, the earlier recommended broadcasting system of fertilizer application (about  $100 \text{ kg NPK (15:15:15)}$  per ha), and the

fertilizer microdosing at 4 to 6 grams per hill of compound fertilizer (NPK) (40 to 60 kg NPK per ha) or 2 grams of Diammonium Phosphate (DAP) per hill (20 kg DAP per ha). The test crops used were millet and sorghum. Plant densities under farmer conditions varied between 5,000 and 6,000 hills per ha while the recommended densities in the microdosing plots ranged from 10,000 to 20,000 hills per ha.

Farmers were given the option to plant their fields whenever they felt that the soil was moist enough for germination of seeds. They used their own densities in the control plots, but were requested to follow the recommended densities in the microdosing plots, with guidance from the field technicians. They also weeded when it was time to do so, in some cases, on the advice of field technicians. Harvesting was done by farmers under the supervision of field technicians. Data collection was done by the field technicians.

In Burkina Faso, 30 villages and 210 farmers in the northern, Central North Zone were involved in these studies. In Mali the on-farm trials were carried out in 44 villages in the region of Mopti, Segou, Koulikoro, Mande and Beledougou with 321 farmers. In Niger, approximately 1,536 demonstrations and field experiments were established in 254 villages in five departments in southern Niger, namely Tillabery, Dosso, Tahoua, Maradi and Zinder.

#### *Socio-economic assessment*

In addition to the field trials, a socio-economic evaluation was carried out to assess the economic performance of the fertilizer microdosing technology. In November/December 2004, surveys were conducted to assess the effect of input shops on fertilizer use and crop yield. These surveys involved 10 villages and 10 input shops.

#### *Capacity building activities*

Field technicians, extension agents and farmers in all the three participating countries were trained in the laying out of the demonstration plots and farmers field schools and the appropriate method of using the fertilizer microdosing technology. These training sessions consisted of demonstrating to them in the field how to measure the recommended rate of fertilizer (microdose), how to apply it correctly and how to manage the field after sowing. Emphasis was also put on the best way of collecting agronomic as well as socio-economic data from the trials set up. Several training sessions were given to farmers organizations on the warrantage system.

## **Results**

### *Microdosing performance by agro-ecological zones*

In all the three agro-ecological zones- Sahelian (400-600 mm), Sudano-Sahelian (600-1000 mm) and Sudano-Guinean (> 1000 mm) sorghum under the microdose yielded higher than under the earlier recommended rates of broadcasting and the farmers traditional practice. The yield advantage of the microdose over the farmers practice varied from 50 to 100 %. As expected, yields were generally higher in the wetter Sudano-Guinean zone (1500 kg ha<sup>-1</sup>) than in the drier Sahelian zone (750 kg ha<sup>-1</sup>). This is due to the higher rainfall amount and to the better distribution of the rainfall in the Sudano-Guinean zone during the growing season, which reduces the risk of crop failure.

### *Burkina Faso*

#### Grain yields

The microdose treatments yielded, on average, higher than the farmers traditional practice. The yield advantage of millet ranged from 44 % in 2002 to 101 % in 2005 while sorghum grain yields under microdose were 47 % and 106 % higher than the control in 2002 and 2005, respectively. Sorghum and millet performed better in 2005 due to a better rainfall distribution during the growing period. In 2006 millet and sorghum grain yields were 64 % and 90 % higher under microdose than with the farmers practice.

#### Net gains from microdosing

Farmers obtained returns from their millet with microdose that were three times higher than the revenue from the broadcasting method (12,575 FCFA ha<sup>-1</sup> as compared to 5175 FCFA ha<sup>-1</sup>). The net gains for sorghum were approximately 2.5 times higher with microdose (22780 FCFA ha<sup>-1</sup> vs 9255 FCFA ha<sup>-1</sup>).

### *Mali*

#### Grain yields

Sorghum and millet performed better under microdose than with the broadcasting method and farmers traditional practice. In 2002, millet and sorghum grain yields with the microdose were, on average, 61 % and 107 % higher than the control, respectively. In 2003, millet and sorghum grain yields from the micro-dosing treatments were 90 % and 69 % higher than the farmers practice, respectively.

### Net gains from microdose

Millet under microdose gave net monetary gains of 119,690 FCFA ha<sup>-1</sup> which were 68 % higher than the net returns from the traditional practice (71,167 FCFA ha<sup>-1</sup>) and 33 % higher than the net gain from the broadcasting technique (89,959 FCFA ha<sup>-1</sup>).

### *Niger*

#### Grain yields

In all agro-ecological zones, microdosing resulted in significant increase in grain yield. There is significant yield increase at individual farmers' level due to microdosing of fertilizers. Grain yield increment from microdosing treatment over the control was as high as 89% with an average of 44% or about 300 kg ha<sup>-1</sup>. Approximately half of the farmers (44%) reported yield increase of at least 50%, which is double the yield obtained from the farmers practice.

#### Net returns from microdosing

In 2002, net returns were 74650 FCFA per ha for DAP + Urea, 65,642 FCFA per ha for DAP, 62,619 FCFA per ha for NPK and 51,745 FCFA per ha for the control. Net profits were, on average, 44% and 121% higher with the microdose than under the control plots in 2002 and 2003, respectively.

#### *Effect of presence of input shops on fertilizer use and crop performance*

It was observed that the presence of input shops in a village has a positive effect on the intensity of fertilizer use as well as the crop yields. On average 5.52 kg of fertilizer per ha were used by farmers where input shops are established as compared to only 3.32 kg per ha in areas with no input shops. This translates to a higher grain yield from millet (541 kg ha<sup>-1</sup>) where there are input shops whereas grain yields were lower (486 kg ha<sup>-1</sup>) in areas with input shops. The presence of input shops where small packs of fertilizers (1, 2, or 5 kg of small pack) are sold enables farmers with limited resources to afford these small packs instead of trying to purchase 50 kg bags of fertilizers that are out of their reach financially.

#### *'Warrantage' or Inventory Credit System*

The Warrantage scheme enables the establishment of a link between credit and cereal grain markets. This credit facility removes the barriers to the adoption of soil fertility restoration technologies. Farmers can have access to credit to enable them purchase external inputs such as fertilizers and invest in income generating activities like fattening of small ruminants, horticulture, trading, etc., while using the stored grains to get higher prices at a time when the market supply begins to decline. In order to make inputs accessible to farmers, sustainable farmer-based enterprises and cooperative organizations are developed, storage facilities and input shops (boutique d' intrants) are built, credit and savings schemes are also developed. These facilities are managed by members of these cooperatives. Farmers were able to make substantial benefits from practicing the warrantage system in Mali.

#### *Conclusions*

The fertilizer microdosing technology has shown its potential in all the three countries, namely Burkina Faso, Mali and Niger where it was tested, demonstrated and promoted. Overall millet and sorghum grain yields were 50 to 120 % higher with microdosing than with the earlier recommended fertilizer broadcasting rates and farmers' traditional practices. Microdosing coupled with the warrantage system (credit scheme and input shops) is an entry point for the green revolution in Africa. It is a simple but efficient technology that is readily accessible by farmers. Farmers achieved net profits from microdosing of up to 130 % higher than with their traditional practice or the broadcasting method. The technology has reached more than 15,000 farmers in the three participating countries.

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Jupiter Ndjeunga<sup>1</sup>, Fatondji Dougbedji<sup>1</sup>, Bruno Gerard<sup>1</sup>, Diakala Sogodogo<sup>6</sup>,  
Jean-Baptiste Sibiry Taonda<sup>4</sup>, Karamako Sako<sup>7</sup>, Sandinan Boubacar<sup>8</sup>,  
Adamou Abdou<sup>2</sup> and Saidou Koala<sup>1</sup>

#### *Annual Milestones*

**Activity 9.2.1.7 Pearl millet yield as affected by corralled organic manure, mineral fertilizer microdose and variety in West Africa**

Organic amendments constitute the principal source of nutrients for smallholder subsistence agriculture in the drylands of sub-Saharan Africa (SSA), as the high costs of inorganic fertilizers limit their use. Unfortunately, throughout the countries of the Sahel there are competing demands for organic amendments, particularly animal manures which are often burnt as a fuel source that limit its availability. Because of this limited availability, it is essential to seek ways of improving the limited resources available, even though corralling of cattle results in its concentration on small areas (10–20 t ha<sup>-1</sup> application rates). One method that has proven successful in southern Africa (Ncube et al. 2007)<sup>6</sup> is the judicious combination of organic and inorganic fertility amendments. However, work is required in the different agricultural zones of SSA to determine the correct combinations of both sources of nutrients, and the right cereal varieties to grow. In West Africa our focus has been on short duration improved millet varieties, that can help escape some of the adverse effects of the regions erratic rainfall patterns.

We studied the effects of organic amendment (corralling), mineral fertilizer (microdose) and variety on millet yield and water use at ICRISAT Sadore in the 2007 rainy season. The experiment involved 4 organic fertilizer rates (0, 2, 4, 8 t ha<sup>-1</sup>); 2 mineral fertilizer rates (0, Di-ammonium phosphate (DAP) as microdose) and 4 millet varieties (ICMV IS 89305, Sosat-C88, GB 8735, local). Initial results are summarized in Table 9.2.1.7.1. The lowest straw yield was recorded with GB-8735, a characteristic of this variety. Application of fertilizer microdose doubled straw yield in all varieties except for Sosat-C88. Head yield ranged from ½ to 1 Mg in the absolute control.

**Table 9.2.1.7.1: Effect of corralled organic manure, mineral fertilizer microdose and variety on millet straw and head yield; Sadore 2007**

| Organic Fertilizer   | Mineral Fertilizer | GB-8735 |      | ICMV-IS89305 |      | Sador local |      | Sosat-C88 |      |
|----------------------|--------------------|---------|------|--------------|------|-------------|------|-----------|------|
|                      |                    | Straw   | Head | Straw        | Head | Straw       | Head | Straw     | Head |
| 0 t ha <sup>-1</sup> | DAP                | 1180    | 1125 | 2609         | 2055 | 2875        | 1719 | 2500      | 2109 |
|                      | Control            | 625     | 672  | 1609         | 1234 | 1672        | 1086 | 2125      | 1164 |
| 2 t ha <sup>-1</sup> | DAP                | 922     | 883  | 2406         | 1852 | 2188        | 1305 | 2312      | 1625 |
|                      | Control            | 523     | 516  | 1773         | 1406 | 2578        | 1383 | 1656      | 1117 |
| 4 t ha <sup>-1</sup> | DAP                | 1234    | 1305 | 2438         | 1883 | 3078        | 1633 | 2203      | 1477 |
|                      | Control            | 1219    | 1141 | 2086         | 1703 | 2516        | 1516 | 2469      | 1703 |
| 8 t ha <sup>-1</sup> | DAP                | 1594    | 1430 | 2539         | 2094 | 3188        | 1859 | 2484      | 1805 |
|                      | Control            | 1016    | 1211 | 2844         | 2219 | 2453        | 1266 | 2547      | 1727 |

Application microdose in the lowest rate of organic manure application resulted in slight increase in straw and head yield for all varieties. The same trend was observed for the highest rate except for variety ICMV IS 89305 where straw yield of the control was higher than with the microdose. Grain data are still under process. Bioeconomic analyses of this first seasons results are under way.

#### *ICRISAT – JIRCAS research*

A joint research program ICRISAT – JIRCAS was initiated in 2006 (a) to study organic matter decomposition in Sahelian soils; (b) to quantify losses of organic matter and nutrients due to termites' activities (c) to study the fate of these nutrients with regard to their availability to crops. The following two treatments were tested: Organic matter type (Millet straw vs. Cattle manure (cow dung)); and litterbag type (2 mm vs. 1 μ mesh size (calico bags)). The smaller mesh size was used to assure that termites do not penetrate the bags. The experiment was laid in a RCBD with 4 replications. The plot size was 6m x 6m = 36m<sup>2</sup>. In each plot, 16 bags were installed 2 m apart from each other. The bags were installed on the soil surface to follow the practice of the farmers in the Sahelian conditions, who either leave millet straw on the soil surface or broadcast the organic manure through corralling. An initial sampling occurred 2 weeks after planting, and then monthly, with two litterbags removed for analyses on each sampling occasion. Sampling occurred at 2 weeks interval. From that point on, samples were collected every month. Initial results for the first year of this experiment (Figure 9.2.1.7.1) clearly show that litter quality was predominant in influencing the decomposition trend, as manure

<sup>6</sup> Ncube B, Dimes J, Twomlow S, Mupangwa W and Giller K. 2007. Raising The Productivity Of Smallholder Farms Under Semi-Arid Conditions By Use Of Small Doses Of Manure And Nitrogen: A Case Of Participatory Research. *Nutrient Cycling in Agro-ecosystems* 77:53-67.

decomposed much quicker than millet straw particularly in the larger mesh size. There was hardly any difference in the trend of litter decomposition in the smaller mesh size, which suggests that soil macro-fauna play a big role in the decomposition of organic amendments.

D Fatondji

#### **Activity 9.2.1.8 A protocol for Screening Genotypic variation in P acquisition in Pearl Millet**

A protocol has been set up to screen genotypic variation for P acquisition from low P soil in pearl millet. The protocol is reported in detail in Project 5. This protocol has been used to investigate the effect of an application of soluble P to the root of a young pearl millet seedling at emergence (1000  $\mu\text{L}$  of a 32 mM  $\text{KH}_2\text{PO}_4$  solution, equivalent to about 10 times the amount of P available in a pearl millet seed). A simple hypothesis to support this work is that small seeded crops such as pearl millet have little nutrient reserve to establish in a soil, and may have more difficulties to establish in low fertility soils than large seeded crops. Results are very promising because the localized placement of P brought about an increase in biomass in all soils tested (varying in Olsen P content from 1.0 to about 4.0 ppm), with variation in the magnitude of the effect across soils, in certain cases more than a 3-fold increase in biomass over the 0 L treatment.

A practical application of this localized placement has been worked out, where pearl millet seeds are coated with a soluble source of P ( $\text{KH}_2\text{PO}_4$ ) at different rates. With a target of about 10-20 times the amount of P per seed, equivalent to about 0.01 mg P, based on a seed P content of 0.4% (mean across 20 lines) and a seed individual weight of 2 mg), a seed coating application would correspond to 170-340 g of granular  $\text{KH}_2\text{PO}_4$  per kilogram of seeds. Therefore, we tested an application of 150 and 300 g  $\text{KH}_2\text{PO}_4$  per kg of seeds, in two soils (RL24-A and RL24-E, with respectively 0.8 and 2.1 ppm Olsen. The response of plant growth to these applications was dramatic, especially in the early stages of growth (see Figure 9.2.1.7.1). The experiment was carried out in 8" pots, with 3 plants per pot and the effect of coating was less visible as the experiment went, very likely because of the limited amount of soil available to tap P. Yet, the plant growth of seed coated millet at harvest (40 days after sowing) was still up to 60% higher than without any coating treatment. The response was more marked in RL24-A than in RL24-E, which suggested that the coating treatment may not bring about an effect on plant growth in less deficient soils. It is hoped that the results of this work will help overcome establishment problems for pearl millet in reduced tillage/conservation agriculture systems, where it appears minimal soil disturbance exacerbates low soil P conditions.



**Figure 9.2.1.8.1. HHB67 hybrid either coated (left) or not (right) with a 300 g  $\text{KH}_2\text{PO}_4$  per kg of seeds treatment in low P soil from RL24-A field (with 0.8 ppm Olsen)**

Vincent Vadez and Padmaja Karanam

#### **Activity 9.2.1.9 Enhanced Productivity and Incomes through Balanced Nutrition in Karnataka Watersheds**

To characterize the fertility status of soils under dryland agriculture in the semi-arid regions of India, we collected 3622 soil samples from farmers' fields in watersheds, spread in several districts of Andhra Pradesh (5 districts), Karnataka (5 districts), Tamil Nadu (5 districts), Rajasthan (3 districts), Madhya Pradesh (2 districts) and Junagadh district in Gujarat. Results of the analysis of soil samples (Table 9.2.1.9.1) showed that almost all

farmers' fields sampled were low in organic carbon (C) and low to moderate in extractable phosphorus (P), but generally adequate in extractable potassium (K). The widespread deficiencies of sulfur (S), boron (B) and zinc (Zn) was most revealing; the deficiencies of these nutrients varied with nutrient, district and state. The deficiencies of S, B and Zn nutrients were more widespread in farmers' fields in Andhra Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu, Haryana and Gujarat than in the Rajasthan watersheds. Our results demonstrate that crops grown under rainfed agriculture in the semi-arid tropical regions of India not only face water shortages and deficiencies of major plant nutrients (N and P), but they also suffer from multi-nutrient deficiencies of S, B and Zn.

**On-farm crop responses to balanced nutrition:** Several on-farm trials were undertaken during 2006 kharif viz., finger millet (17), maize (22), groundnut (17) and soybean (7). In all the cases, significant yield responses were obtained with balanced nutrition (Farmers input+S+B+Zn+NP) over farmers input (Sub-optimal NP). Finger millet grain yield increased from 1698 to 2173 kg ha<sup>-1</sup> (28%), maize yield increased from 2638 to 5339 kg ha<sup>-1</sup> (47%), groundnut pod yield increased from 1084 to 1451 kg ha<sup>-1</sup> (34%) and soybean yield increased from 1116 to 2654 kg ha<sup>-1</sup> (138%).

#### *Nutrient uptake by different crop*

Substantial increase in nutrient uptake by the different crops was observed in response to balanced nutrition compared to farmers input. Nitrogen uptake in finger millet increased from 49 to 75 kg ha<sup>-1</sup> (52%), in maize from 76 to 117 kg ha<sup>-1</sup> (50%), in sunflower from 48 to 93 kg ha<sup>-1</sup> (93%), in soybean from 127 to 216 kg ha<sup>-1</sup> (70%) and in groundnut from 72 to 111 kg ha<sup>-1</sup> (55%). Similarly P uptake increased by 33% in finger millet, 28% in maize, 89% in sunflower, 97% in soybean and 43% in groundnut. Potassium uptake was also increased by 44 % in finger millet, 31% in maize, 120% in sunflower, 84% in soybean and 38% in groundnut. Sulphur uptake was increased by 72% in finger millet, 36% in maize, 62% in sunflower, 121 % in soybean and 51% in groundnut. Similarly, Zn uptake and B uptake increased substantially with balanced nutrition as compared to farmers' input.

#### *Economics of Balanced nutrition*

Because of increased yields in different crops due to balanced nutrition, additional income among different crops varied from Rs 6300/- (Finger millet) to Rs 21,000/- (Sunflower) (Table 9.2.1.9.2).



**Table 9.2.1.9.1. Extractable (available) zinc (Zn), boron (B) and sulfur (S) status of soil in farmers' fields in different locations in six states of India.**

| Locations            | No. of farmers fields | Extractable Zn ( $\text{g g}^{-1}$ ) |     |      | Extractable B ( $\text{g g}^{-1}$ ) |      |     | Extractable S ( $\text{g g}^{-1}$ ) |  |      |       |
|----------------------|-----------------------|--------------------------------------|-----|------|-------------------------------------|------|-----|-------------------------------------|--|------|-------|
|                      |                       | Min                                  |     | Max  | Min                                 |      | Max | Min                                 |  | Max  |       |
| Andhra Pradesh       |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Nalgonda             | 176                   | 0.08                                 |     | 2.20 |                                     | 0.02 |     | 0.8                                 |  | 1.4  | 50.5  |
| (% deficient fields) |                       |                                      | 94  |      |                                     |      | 99  |                                     |  |      | 89    |
| Mahabubnagar         | 262                   | 0.12                                 |     | 1.38 |                                     | 0.02 |     | 0.74                                |  | 1.1  | 30.8  |
| (% deficient fields) |                       |                                      | 83  |      |                                     |      | 98  |                                     |  |      | 89    |
| Kurnool              | 223                   | 0.10                                 |     | 1.18 |                                     | 0.04 |     | 1.48                                |  | 1.3  | 24.7  |
| (% deficient fields) |                       |                                      | 81  |      |                                     |      | 92  |                                     |  |      | 88    |
| Madhya Pradesh       |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Vidisha              | 12                    | 0.16                                 |     | 0.96 |                                     | 0.65 |     | 1.2                                 |  | 3.2  | 5.35  |
| (% deficient fields) |                       |                                      | 92  |      |                                     |      | 0   |                                     |  |      | 100   |
| Dewas                | 24                    | 0.12                                 |     | 0.56 |                                     | 0.2  |     | 0.8                                 |  | 3.9  | 9.5   |
| (% deficient fields) |                       |                                      | 100 |      |                                     |      | 96  |                                     |  |      | 100   |
| Guna                 | 18                    | 0.24                                 |     | 1.74 |                                     | 0.6  |     | 2.2                                 |  | 2.6  | 14.2  |
| (% deficient fields) |                       |                                      | 78  |      |                                     |      | 0   |                                     |  |      | 89    |
| Rajasthan            |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Bundi                | 36                    | 0.20                                 |     | 1.8  |                                     | 0.1  |     | 0.98                                |  | 3.2  | 50.9  |
| (% deficient fields) |                       |                                      | 67  |      |                                     |      | 72  |                                     |  |      | 72    |
| Gujarat              |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Bharuch Kutch        | 82                    | <0.2                                 |     | 2.45 |                                     | 0.06 |     | 0.49                                |  | 1.1  | 150.4 |
| (% deficient fields) |                       |                                      | 85  |      |                                     |      | 100 |                                     |  |      | 40    |
| Haryana              |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Gurugaoan            | 30                    | <0.2                                 |     | 0.87 |                                     | 0.09 |     | 0.85                                |  | <0.3 | 90.8  |
| (% deficient fields) |                       |                                      | 89  |      |                                     |      | 93  |                                     |  |      | 60    |
| Tamil Nadu           |                       |                                      |     |      |                                     |      |     |                                     |  |      |       |
| Tirunevelli          | 12                    | <0.2                                 |     | <0.2 |                                     | 0.08 |     | 0.26                                |  | <0.3 | 3.4   |
| (% deficient fields) |                       |                                      | 100 |      |                                     |      | 100 |                                     |  |      | 100   |

**Table 9.2.1.9.2. Additional benefit due to balanced nutrition in different crops**

| Crop          | Additional benefit resulting from increased yield due to balanced fertilization ( $\text{Rs ha}^{-1}$ ) |
|---------------|---------------------------------------------------------------------------------------------------------|
| Finger millet | 6300                                                                                                    |
| Sunflower     | 21000                                                                                                   |
| Maize         | 16000                                                                                                   |
| Groundnut     | 15200                                                                                                   |
| Soybean       | 14410                                                                                                   |

*Target Output 9.2.2 Sahelian Eco-farm. 1<sup>st</sup> proof of concept tested and validated and report drafted.*

### **Background**

The Sahelian Eco-Farm (SEF) is an integrated crops-trees-livestock system designed to give solutions to a range of constraints of current crops production systems in the Sahel. These are: Low soil fertility, frequent droughts, low value of main annual crops (coarse grains), and limited supply of animal feed and poor distribution of farm work over the year.

The SEF is based on rows of Australian Acacias (*Acacia colei* or *A. tumida*) and of *Ziziphus mauritiana* (a rain-fed fruit tree domesticated in India and named Pomme du Sahel or PDS) intercropped with two or more annual crops. The Acacias provide mulch, fix atmospheric nitrogen and provide root biomass leading to increased soil fertility as well as provision of firewood. The PDS increases income from the system and guarantees income and food during drought years. The annual crops incorporate at least one leguminous species for further improvement of soil fertility. Annual crops are rotated.

#### **Experimental**

A one-hectare experimental SEF was planted at Sadore, the ICRISAT research center in Niger in the year 2002. A traditional “control” where annual crops only were planted without rotation and without trees was established beside the SEF. Four soil fertility treatments were imposed: control, mulch, NPK and mulch plus NPK.

The annual crops were pearl millet, cowpeas and Roselle. Each species was planted in one third of a hectare and rotated each year.

In addition, five pilot SEF plots were planted in five pilot farmers’ fields at different climatic regions of Niger. An economic study was carried out using on-station and on-farm inputs and outputs.

### **Results and conclusions**

*Acacia colei* trees were first cut in 2004. We have gathered yield and other information for four consecutive years.

In all four experimental years yields of annual crops in the SEF was twice to four times higher than in the control depending on species (Figure 9.2.2.1). Somewhat surprising and flying in the face of conventional wisdom that mulching improves yields in water limited environments, the SEF mulch had no significant impacts on overall yields. In the SEF the addition of NPK, in contrast to the control systems had little or no effect on crop yields.

In addition to the yields from the annually sown crops, on hectare of SEF produces one ton of renewable firewood and one ton of mulch on average each season.

The average annual economic performance of the SEF is summarized in Figure 9.2.2.2. The profit from PDS fruit was equal to the total profit from annuals. After PDS trees reach full maturity the profit from fruit will be more than 70% of the system’s profit.

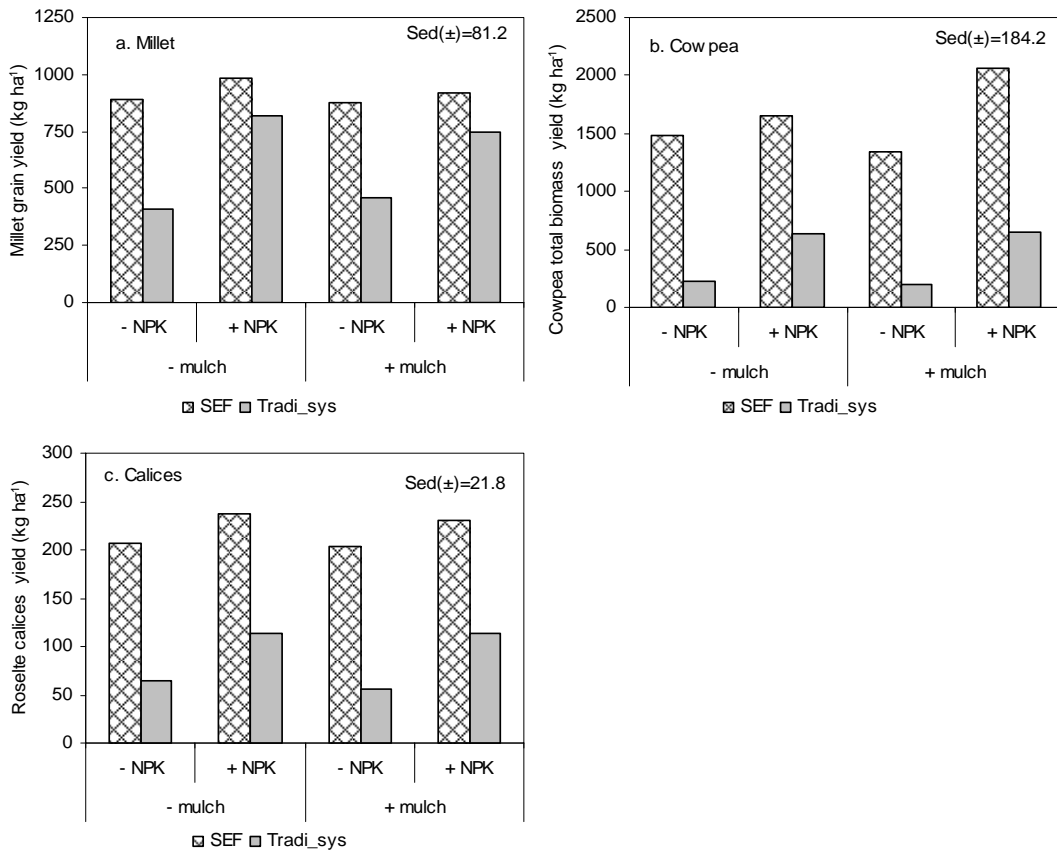
SEF performance was best in 2004 when rain started early and rain distribution was ideal. Annual crop yields declined over the following three years. Each of these years was marked for poorer rain distribution than the previous one. Therefore it is not yet conclusive whether the successive yield decline was due to reduced soil fertility or to poorer rain distribution. We will need at least one more year of good rain distribution to clarify this point.

On-farm performance of SEF was similar to on-station performance.

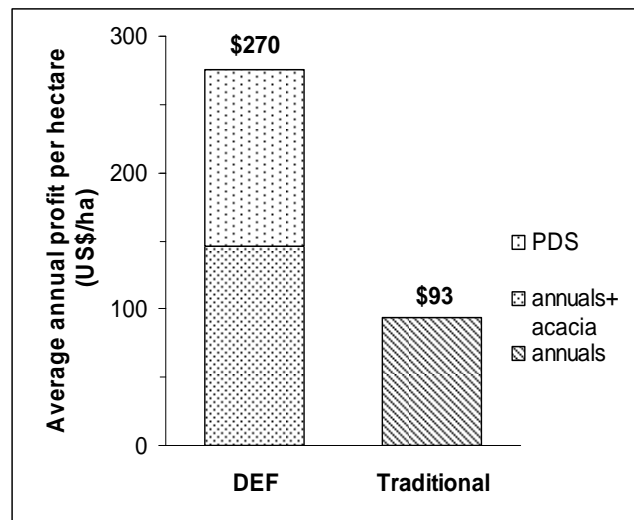
#### **Main conclusions**

The SEF is a very promising INRM system for rainfed crop production in the dry infertile Sahel. However, it is necessary to continue trials for at least two more years before drawing conclusions leading to the up-scaling of this system

The Pomme du Sahel tree is highly adapted to the rainfall amount and distribution of the Sahel and to its soils. Income from these trees can be three times or more higher than income from annuals. The Dryland Fruit Trees Plantation (DFP) is a modification of the SEF. It is based on PDS intercropped with high value annuals. We are starting careful dissemination of this latter system



**Figure 9.2.2.1: Effect of the Dryland Eco-farm system on millet grain, cowpea total biomass and Roselle calices yield; averaged across seasons 2004-2006; Sadore ICRISAT research station. SED is standard error of difference between means**



**Figure 9.2.2.2: Annual profit per hectare in the SEF compared with best traditional system**

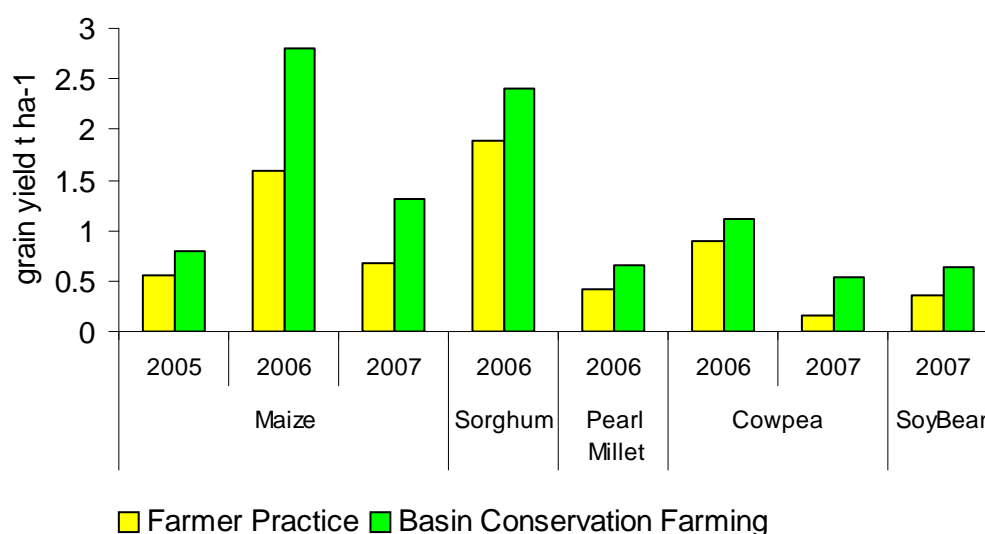
*Annual Milestones for 2007*

**Activity 9.2.2.1 Precision Conservation Agriculture for Vulnerable Farmers in Low-potential Zones**

In the drier areas of southern Africa, farmers experience drought once every two to three years. Relief agencies have traditionally responded to resulting famines by providing farmers with enough seed and fertilizer to enable them to re-establish their cropping enterprises. But, the absence of appropriate land and crop management interventions, did not lead to sustained gains in productivity and incomes for these vulnerable farmers.

ICRISAT, in collaboration with the national extension department (AGRITEX) and 13 non-governmental organizations (NGOs) in Zimbabwe, has been testing modifications of conservation farming techniques that create what can be called precision conservation agriculture (PCA). These strategies for farmers in low potential zones, where most of the most resource poor and vulnerable farm households exist, encompass three major principles; (i) minimum tillage – for instance, using planting basins which harvest and concentrate limited water for use by the plant, (ii) the precision application of nutrient resources such as small/micro doses of nitrogen-based fertilizer, manure, compost and mineral compound fertilizer to achieve higher nutrient use efficiency, and (iii) combining improved fertility with improved seed for higher productivity. These basic principles are taught to farmers who choose crop mixes adapted to their local conditions and household resource constraints. PCA spreads labor for land preparation over the dry seasons and encourages more timely planting, resulting in reduction of peak labor loads at planting, higher productivity and incomes.

Over three years, these simple technologies have been promoted by NGOs and AGRITEX and consistently increased average yields by 15 to 300 percent in more than 30,000 farm households (Figure 9.2.2.1.1), with the yield increase varying by rainfall regime, soil types and fertility.



**Figure 9.2.2.1.1. Cereal and legume grain yield responses to conventional farmer practice and planting basins over three seasons averaged across 13 districts in semi-arid areas in Zimbabwe**

Use of volunteer farmer clusters rather than lead farmers or farmer field schools to demonstrate these principles, is leading to higher spontaneous uptake. For instance, in two wards in southern Zimbabwe, with demonstration by 10 percent of farms, more than 90% spontaneous uptake has taken place in which 1,000 farm households invest their own capital and other resources. Although the area under PCA is not large enough yet to create a marketable surplus, food security has increased substantially. As expected, these farmers are adopting these techniques little by little. The area they have applied PCA has doubled from 1/4 to 1/2 acre and this small area is accounting for 35% of household cereal requirements on average. PCA also enables diversification in

cropping patterns and more reliable legume production. Returns to labor has been about 2 times higher than conventional practices on average (Table 9.2.2.1.1). Although returns to microdosing fertilizer alone can be higher in better than average rainfall years, making planting basins every year leads to build up of soil fertility and organic matter over time and a more sustainable system.

Rather than simply handing free inputs to farmers, teaching farmers these precision conservation agriculture principles enables them to apply inputs (water, fertilizer and seed) more efficiently. The pursuit of input use efficiency provides higher and more sustainable productivity gains needed to achieve better food security in drought prone farming systems.

The research has been published in

**Belder P, Twomlow SJ and Hove L.** 2007. Early evidence of improved soil quality with conservation farming under smallholder farming conditions in Zimbabwe. Paper Presented at the ICID Conference, November 2007, Johannesburg, South Africa.

**Hove L and Twomlow S.** 2007. Is Conservation Agriculture an Option for Vulnerable Households in Southern Africa? FAO workshop in Damascus, Syria.

**Mazvimavi K, Twomlow S, Murendo C and Musitine T.** 2007. Science in agricultural relief and development programs: The case of conservation farming in Zimbabwe. Paper presented to the Association of African Agricultural Economist Meeting, Accra, Ghana, August 2007.

**Mazvimavi K and Twomlow S.** 2007. Conservation Farming for Agricultural Relief and Development in Zimbabwe. 2008. Pages 169-178 in *No-Till Farming Systems* (Goddard T, Zoebisch MA, Gan YT, Ellis W, Watson A and Sombatpanit S, eds.). Special Publication No. 3, World Association of Soil and Water Conservation, Bangkok, ISBN: 978-974-8391-60-1.

**Mupangwa W, Twomlow S, Hove L and WALKER S.** 2007. Effect of minimum tillage and mulching on maize (*Zea mays L.*) yield and water content of clayey and sandy Soils. *Journal of Physics and Chemistry of the Earth* 32:1127-1134.

**Twomlow S, Rohrbach D, Hove L, Mupangwa W, MASHINGAIDZE N, Moyo M and Chiroro C.** 2007. Conservation farming by basins breathes new life into smallholder farmers in Zimbabwe. *In Land and Water Management for Sustainable Agriculture* (Mapiki A and Nhira C, eds.). Proceedings of the EU/SADC Land and Water Management Applied Research and Training Programme's Inaugural Scientific Symposium, Malawi Institute Management, Lilongwe, Malawi, 14 – 16 February 2006. Paper 7.2

**Table 9.2.2.1.1. Sensitivity analysis for conservation versus conventional practices under high-, normal, and low-rainfall situations in Zimbabwe. (Microdosing with 28 kg N ha<sup>-1</sup>)**

|                  |          | Conservation Farming |               | Conventional Farmer practice |
|------------------|----------|----------------------|---------------|------------------------------|
|                  |          | First year           | Second + year |                              |
| High Rainfall    |          |                      |               |                              |
| Maize grain      | Kg/ha    | 2100                 | 2900          | 1650                         |
| Stover           | Kg/ha    | 0                    | 0             | 577.50                       |
| Gross Margin     | US\$/ha  | 643.71               | 960.45        | 637.52                       |
| Cost per tonne   | US\$/ton | 90                   | 70            | 60                           |
| Returns to Labor | US\$/day | 5.33                 | 7.36          | 10.17                        |
| Normal Rainfall  |          |                      |               |                              |
| Maize grain      | Kg/ha    | 1750                 | 2200          | 790                          |
| Stover           | Kg/ha    | 0                    | 0             | 175                          |
| Gross Margin     | US\$/ha  | 503.71               | 680.45        | 257.40                       |
| Cost per tonne   | US\$/ton | 110                  | 90            | 120                          |
| Returns to Labor | US\$/day | 4.36                 | 5.47          | 4.63                         |
| Low Rainfall     |          |                      |               |                              |
| Maize grain      | Kg/ha    | 1520.00              | 1780.00       | 368.80                       |
| Stover           | Kg/ha    | 0                    | 0             | 129.08                       |
| Gross Margin     | US\$/ha  | 411.71               | 512.45        | 71.23                        |

|                  |          |      |      |      |
|------------------|----------|------|------|------|
| Cost per tonne   | US\$/ton | 130  | 110  | 250  |
| Returns to Labor | US\$/day | 3.73 | 4.34 | 1.92 |

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### Activity 9.2.2.2: Evaluation of Land and Water Management Systems and Hydrological Monitoring in Sujala Watersheds, Karnataka , India

ICRISAT, in partnership with the Sujala watershed project, NGOs and farmers, is implementing improved watershed management technologies in Sujala Watersheds in five districts of Karnataka (Kolar, Tumkur, Chitradurga, Dharwad and Haveri). Alfisols and Vertisols are two major soil types in Karnataka. The current crop yields under rainfed conditions are very low and variable. There is a need for field based improved land and water management technology that can protect the soil from erosion and provide *in-situ* water control.

#### Crop Responses to field based land and water management trials

During 2006-07, field based land and water management trials and hydrological monitoring of runoff and soil loss were undertaken in Sujala watersheds along with capacity building activities for the effective implementation of farmers' participatory trials. The land and water management treatments implemented on farmers' fields and subsequent crop responses are summarized in Table 9.2.2.2.1. The increase in crop yields with cultivation across slopes with conservation furrow system, and with different crops like maize, soybean, groundnut and finger millet were 12-20% over farmers' practice, while with the broad-bed and furrow system with maize, 31 % increase over farmers practice was recorded.

**Table 9.2.2.2.1. Crop yield responses to different land and water management systems in 2006-07**

| District/<br>Watershed | Crop yields (t ha-1)       |                                                               |                               |               |
|------------------------|----------------------------|---------------------------------------------------------------|-------------------------------|---------------|
|                        | T1<br>Farmers'<br>practice | T2<br>Cultivation across slope<br>with conservation<br>furrow | T3<br>Broadbed- and<br>furrow | Crop          |
| Haveri                 |                            |                                                               |                               |               |
| Aremallapur            | 3.11                       | 3.61 (16) *                                                   | -                             | Maize         |
| Hedigonda              | 4.03                       | 4.56 (13)                                                     | -                             | Maize         |
| Dharwad                |                            |                                                               |                               |               |
| Parsapur               | 1.50                       | 1.80 (20)                                                     | -                             | Soybean       |
| Kolar                  |                            |                                                               |                               |               |
| Machenahalli           | 0.88                       | 1.01 (14)                                                     |                               | Groundnut     |
| Machenahalli           | 2.22                       | 2.59 (17)                                                     |                               | Finger millet |
| Diggur                 | 1.01                       | 1.20 (19)                                                     |                               | Groundnut     |
| Chikkanahalli          | 1.19                       | 1.39 (17)                                                     |                               | Groundnut     |
| Venkateshalli          | 0.95                       | 1.07 (12)                                                     |                               | Groundnut     |
| Tumkur                 |                            |                                                               |                               |               |
| Kanakapura             | 1.29                       | 1.49 (15)                                                     | -                             | Groundnut     |
| Chitradurga            |                            |                                                               |                               |               |
| Maradihalli            | 1.29                       | -                                                             | 4.62 (31)                     | Maize         |
| Toparamalige           | 3.53                       |                                                               | 4.56 (30)                     | Maize         |

(\* Values in parentheses are the % increase over T1)

The cost-benefit ratios for different land treatments and crops are shown in Table 9.2.2.2.2. The average cost benefit ratio in improved land management system was 1.89 and in farmers practice it was 1.64 with an increase of 15.8 %.

**Table 9.2.2.2.2. Comparison of benefit-cost ratio in different land management systems, Sujala watersheds, (2006-2007)**

| District    | Watershed    | Crops     | Benefit cost (B:C) ratio |                   |              |
|-------------|--------------|-----------|--------------------------|-------------------|--------------|
|             |              |           | Farmers practice         | Improved practice | Increase (%) |
| Chitradurga | Maradihalli  | Sunflower | 1.78                     | 2.05              | 15.2         |
|             | Toparamalige | Maize     | 1.83                     | 2.05              | 12.0         |
| Haveri      | Aremallapur  | Maize     | 1.74                     | 2.06              | 18.4         |

|             |               |               |             |             |             |
|-------------|---------------|---------------|-------------|-------------|-------------|
| Dharwad     | Anchatageri   | Soybean       | 1.77        | 2.18        | 23.2        |
| Tumkur      | Kanakapura    | Groundnut     | 1.36        | 1.62        | 19.1        |
| Kolar       | Belaganahalli | Groundnut     | 2.14        | 2.34        | 9.5         |
|             | Belaganahalli | Finger millet | 1.26        | 1.4         | 11.1        |
|             | Machanhalli   | Finger millet | 1.22        | 1.44        | 18.0        |
| <b>Mean</b> |               |               | <b>1.64</b> | <b>1.89</b> | <b>15.8</b> |

The average additional expenditure incurred for imposing land and water management treatments, such as cultivation across slope with conservation furrow was Rs 300 per ha and for broad-bed and furrow system was Rs 600 per ha. The returns on this additional investment for putting the land and water management treatment are shown in Table 9.2.2.2.3. The highest returns were reported at Aremallapur watershed in Haveri district for cultivation across slope with conservation furrow system in maize crop.

**Table 9.2.2.2.3. Returns on additional investment for imposing land and water management treatment at Sujala watersheds, Karnataka.**

| District    | Watershed     | Land and water management treatment (crop) | Returns on additional investment |      |
|-------------|---------------|--------------------------------------------|----------------------------------|------|
|             |               |                                            | (Rs ha <sup>-1</sup> )           | (%)  |
| Chitradurga | Maradihalli   | BBF (Sunflower)                            | 3100                             | 517  |
|             | Toparamallige | BBF (Maize)                                | 3120                             | 520  |
| Haveri      | Aremallapur   | Conservation furrow (Maize)                | 3300                             | 1100 |
| Dharwad     | Anchatageri   | Conservation furrow (Soybean)              | 3180                             | 1060 |
| Tumkur      | Kanakapura    | Conservation furrow (Groundnut)            | 3100                             | 1033 |
| Kolar       | Belaganahalli | Conservation furrow (Groundnut)            | 2700                             | 900  |
|             | Belaganahalli | Conservation furrow (Finger millet)        | 2300                             | 766  |
|             | Machanhalli   | Conservation furrow (Finger millet)        | 1550                             | 516  |

#### Hydrological Responses to field based land and water management trials:

Hydrological data (runoff volume and peak rate of runoff and soil loss) play an important role in the design of cost-effective and efficient hydraulic structures, and is used to assess the potential of runoff harvesting and groundwater recharge, and to assess the impact of watershed interventions. Hydrological monitoring stations were established in 2005 and data on runoff and soil loss have been recorded since for rainfall event that generated runoff in each of the watersheds.

Seasonal hydrological responses for 4 watersheds are summarized in Table 9.2.2.2.4. At most of the locations runoff occurred during the early part of the season, which suggests that there is need to control early runoff in watersheds. Data also suggest that at a few locations there is a good potential of harvesting runoff with low-cost water harvesting structures.

**Table 9.2.2.2.4. Rainfall, runoff and soil loss from Sujala watersheds, Karnataka, 2006-2007**

| District (Watershed)      | Rainfall (mm) | Runoff (mm) | Runoff as % of seasonal rainfall | Peak runoff rate (m <sup>3</sup> s <sup>-1</sup> ha <sup>-1</sup> ) | Soil loss (t ha <sup>-1</sup> ) |
|---------------------------|---------------|-------------|----------------------------------|---------------------------------------------------------------------|---------------------------------|
| Haveri (Aremallapur)      | 350           | 44          | 12.6                             | 0.011                                                               | 2.01                            |
| Dharwad (Anchatageri)     | 652           | 20          | 3.1                              | 0.07                                                                | 1.24                            |
| Kolar (Huttur)            | 547           | 22          | 4.0                              | 0.025                                                               | 0.80                            |
| Chitradurga (Toparmalige) | 508           | 16          | 3.1                              | 0.011                                                               | 0.66                            |
| <b>Mean</b>               | <b>514</b>    | <b>25.5</b> | <b>5.7</b>                       | <b>0.029</b>                                                        | <b>1.18</b>                     |

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### Activity 9.2.2.3. Impacts of Watershed Interventions on Water Quality

Quality of water in different sources such as tube well, open wells, tanks and ponds were monitored in Hutur (Kolar dist.) and Aremallapur (Dharwad district) in Karnataka and ICRISAT (both black and red soil watersheds) and Kothapally (Rangareddy district) in Andhra Pradesh during 2006-07. These samples were brought to ICRISAT and analyzed for  $\text{NH}_4$ ,  $\text{NO}_3$ , water soluble Na, K, Ca, Mg, S, micronutrients viz., Fe, Cu, Zn, Mn and B and heavy metals like Cd, Co, Ni, Pb, Cr, Li in the Central Analytical Services Laboratory of ICRISAT. Simultaneously, information was collected on crops/cropping systems/ fertilizers/ manures /pesticides/tillage/soil type/slope, etc.

#### *Hudur, Kolar*

In the month of May,  $\text{NO}_3$  content in tube well water ranged from 0.85-13.47  $\text{mg L}^{-1}$ . Out of 6 tube wells surveyed, water in one tube well is not safe for drinking purpose. In the month of June, it further increased to 0.9-16.7  $\text{mg L}^{-1}$ . Two were above safe limits. Water of open tanks was high in Fe content. In the month of May and June it ranged from 1.5-11.5  $\text{mg L}^{-1}$  and 3-6.6  $\text{mg L}^{-1}$  respectively. Heavy metal content was within the permissible limit for drinking as well as irrigation.

#### *Aremallapur, Ranebennur*

There was no  $\text{NO}_3$  pollution found in any of the water bodies. In the month of May and June Na content is high in the bore well water. It was in the range of 138-207  $\text{mg L}^{-1}$  in the month of May and 142-205  $\text{mg L}^{-1}$  in the month of June. In the month of September it decreased. Water in some bore well was above safe limit for drinking. In some bore well Fe and B content was also found higher. There was no heavy metal pollution found in any water bodies.

#### *ICRISAT(both Red and black soil watershed)*

In ICRISAT, ponds contain Fe in the range of 0.02-6.2  $\text{mg L}^{-1}$  in the month of July-August. Red soil tank-2 contains Fe above the safe limits for irrigation (6.2  $\text{mg L}^{-1}$ ) (safe limit upto 5.0  $\text{mg L}^{-1}$ ). Again in the month of Sept-Oct, Fe content in the ponds' water decreased in the range of 0.02-2.8  $\text{mg L}^{-1}$ .  $\text{NO}_3$ , Na and other heavy metals are with in the safe limits for drinking and irrigation purposes in all the water bodies.

#### *Kothapally*

In the month of July  $\text{NO}_3$  content in the borewell ranges from (3.1-24.1  $\text{mg L}^{-1}$ ). This is above the safe limit of drinking.  $\text{NO}_3$  content decreased in the month of August (5.5-9.4  $\text{mg L}^{-1}$ ).

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### Activity 9.2.2.4: Heavy Metal Concentration in Different Soil Types Under Rainfed Production Systems in India

Soil samples from twenty one locations of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) were characterized for availability of total Cd, Co, Cr, Ni, Pb, Cu, Mn and Zn based on profile sampling. The twenty one locations covered agro-ecological regions from 2.3 to 12.3, semi-arid, arid and sub-humid climate, soils of Vertisols, vertic sub-groups, Alfisols, Inceptisols and Aridisols in India. Rainfall ranged from 412 to 3178 mm among locations. Various physico-chemical properties of 21 profiles indicated that most of the locations were low in organic carbon showing less than 0.5 %. Clay content varied widely among soil types. Low organic matter in these soils is one of the important factors contributing to low soil fertility.

Soil profiles represented soil types under major production systems at 21 different dryland centers of AICRPDA considering the variables: production systems, soil taxonomy and fertility status. Representative soil profile samples from the following production systems have been collected: rice, groundnut, soybean, cotton, rabi sorghum, pearl millet, finger millet and maize- based production systems.

The concentration of total heavy metals (Cd, Co, Cr, Ni, Pb, Cu, Mn and Zn) in all the soil samples in India was found between 0.05 to 2681  $\text{mg kg}^{-1}$ . The concentration of Cd was low compared to other heavy metals and ranged between 0.8 to 4.9  $\text{mg kg}^{-1}$ . The concentration of cobalt ranged from 4.8 to 46.6  $\text{mg kg}^{-1}$ , chromium ranged between 31.6 to 246.9  $\text{mg kg}^{-1}$ , nickel ranged between 10.2 to 102  $\text{mg kg}^{-1}$ , lead between 0.05 to 6.8  $\text{mg kg}^{-1}$ , copper between 4.2 to 114.3  $\text{mg kg}^{-1}$ , manganese between 136 to 2681  $\text{mg kg}^{-1}$  and zinc ranged between 8.1 to 129.3  $\text{mg kg}^{-1}$  in soils. Above results suggest that soils from different locations under rainfed production



systems of the country vary widely in the heavy metal status. As soils were low in organic matter and deficient in micro nutrients in several locations, nutrient management strategies should include improving soil organic matter by regular additions of crop residues along with limiting nutrients for improving productivity levels of dryland crops.

Total lead was below critical limit in SK Nagar. Total zinc was below critical limit in Arjia and manganese was below critical limit in Rakh Dhiansar, Anantapur and Arjia. All the other heavy metals (Cd, Co, Cr, Ni and Cu) showed normal range in the soil.

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**Activity 9.2.2.5: Integrate, evaluate and promote IDM options with other crop management technologies (including PVS, IPM and INM) for the management of BGM of chickpea, and foliar diseases of groundnut in participation with farmers**

1. *Farmer's participatory on farm IDM trials in groundnut in Sujala watershed in Karnataka:*  
Based on the previous seasons successes IDM trials were expanded to over 30 farmers in six villages in three districts, Kolar, Tumkur and Chitradurga during the 2007 season in the state of Karnataka. The IDM technology consisted of improved, short duration, management responsive cultivar ICGV 91114, seed treatment with a mixture of Bavistin and thiram (1:1) @ 2.5g kg<sup>-1</sup> seed and foliar application of fungicide Bavistin @ 1g in 1L water and 200 L solution per acre @60-65 days after sowing. The non-IDM plots consisted of local cultivar (TMV 2) and local practices.

Mean severity of foliar diseases (late leaf spot and rust) across locations in Tumkur, Kolar and Chitradurga was 4.8, 5.0 and 4.7 (on a 1-9 rating scale) in IDM plots as compared to 7.4, 7.6, 6.0 in non-IDM plots respectively. The low severity of foliar diseases in Chitradurga was attributed to low rainfall and drought during the active growth stage of the crop.

As a result of this field program, and the associated farmer field days, demand for the cultivar ICGV 91114 from the neighbouring villages and districts is growing. Farmers are very happy to see and know about different diseases of groundnut.

2. *Collaborative research on introduction of chickpea in the RWC in North India:*  
In collaboration with rice and wheat consortium (RWC) and its partner organizations, chickpea trials were conducted in rice fallows in eight villages during the 2007 season. The villages and number of trials were Samani (1 trial), Dudhla (3 trials), Sirsata (4 trials), Karnal (2 trials) in Kurukshetra district, Haryana and Gokulpur (4 trials), Alamgirpur (6 trials), Gadina (6 trials), Kalina (4 trials) in the Meerut district, Uttar Pradesh. Chickpea was intercropped with sugar cane and was planted in two rows on beds in all villages. Vegetative growth of the crop was luxurious with thick canopy in several trials. The crop experienced severe rainfall and cloudy days from 10<sup>th</sup> February to 18<sup>th</sup> March 2007 in the Kurukshetra district. Most of the trials were destroyed due to water stagnation for several days. The crop was very good with luxurious vegetative growth in four villages, Gokulpur, Alamgirpur, Gadina and Kalina in the Meerut district. BGM was observed under dense canopy in all the trials in all the villages visited. Stunt, stem rot and BRR were also recorded in all these locations. Grain yield was higher in the Meerut district than in the Kurukshetra district.
3. *Pigeonpea in legume-wheat cropping system evaluated and up scaled in North Western and Eastern plains of India:*  
In collaboration with rice and wheat consortium (RWC) and its partner organizations, ICRISAT bred extra short duration pigeonpea (ESDP) cultivar, ICPL 88039 was evaluated in farmers fields for its earliness and yields performance in several villages in the districts of Ghaziabad, Meerut, Lalitpur, Varanasi, Gajipur, Balia (Uttar Pradesh); Karnal (Haryana); Bharatpur (Rajasthan). It was sown on raised beds using seed drill as well as broadcasted on flat soil. Optimum plant stand was observed in all the locations irrespective of method of sowing.

In all the trials, ESDP cultivar matured 15-20 days earlier than UPAS 120. Mean grain yield of 1.75-2.0 t ha<sup>-1</sup> was recorded in ESDP cultivar, ICPL 88039 in comparison to 1.0 - 1.35 t ha<sup>-1</sup> in local cultivar UPAS 120. The cultivar was widely accepted by several farmers in all the villages since it is maturing two to three weeks earlier than traditional local cultivar UPAS 120 and is well suited for rotation with

wheat and thus diversifying rice-wheat cropping system to pigeonpea-wheat cropping system. No disease was observed in the districts Ghaziabad, Meerut, Bharatpur but sporadic incidence of SM and very low incidence of fusarium wilt was noticed in Lalitpur, Varanasi and Gajipur districts. In the Balia district in addition to SM and wilt, moderate severity of BGM was observed.

*Activity 9.2.2.6. Modeling hydraulic properties of sandy soils of Niger using pedotransfer functions (output from USAID Linkage grant 'Spatial modeling of regional soil water balance from remotely sensed data and indigenous knowledge to predict crop stress and mitigate food deficit in Niger, 2002-2005).*

Direct determination of soil hydraulic properties is often costly and laborious hence the use of indirect methods such as pedotransfer functions (PTFs). Despite progress made in PTF development in general, little evaluation of PTFs has been done for the sandy soils of Niger. We tested the ability of three PTFs, (Campbell, van Genuchten, and Vauclin) to determine soil water retention and unsaturated hydraulic conductivity (K) for sandy soils at two villages (Banizoumbou and Bagoua) in Niger. Modeled K was compared to K estimated from neutron probe readings at 1.4 m; and modeled moisture retention was compared to lab measurements derived from the hanging water column method and pressure plate apparatus for the following depth intervals: 0–30, 30–60, and N60 cm at Banizoumbou; and 0–30, 30–120, and N120 cm at Bagoua. The Campbell PTF resulted in lower root mean square error (RMSE) ( $0.05\text{--}0.06\text{ m}^3\text{ m}^{-3}$ ) for soil moisture retention for the three depth intervals at the two sites and performed better than the van Genuchten function (RMSE  $0.06\text{--}0.07\text{ m}^3\text{ m}^{-3}$ ) for Bagoua soils which had higher sand content. The van Genuchten PTF consistently overestimated dry regime moisture retention for the three depth intervals especially at Bagoua, but performed well for the wet regime. The Campbell and Vauclin PTFs underestimated K (RMSE  $0.61\text{--}1.01\text{ mm d}^{-1}$ ) at both sites whereas the van Genuchten model was close to field measurements (RMSE  $0.26\text{--}0.47\text{ mm d}^{-1}$ ). These results show that the Campbell model is a cheaper alternative to direct measurement of moisture retention and the van Genuchten function can be used to estimate K for Niger's sandy soils with modest accuracy.

Research published in Geoderma as: Manyame C, Morgan CL, Heilman JL, Fatondji D, Gérard B and Payne WA. 2007. Modeling hydraulic properties of sandy soils of Niger using pedotransfer functions. Geoderma, 141(3-4):407-415.

Suresh Pande and Collaborators

#### **Activity 9.2.2.7: Protecting cotton on-farm with biological approaches -OP Rupela**

Synthetic chemical pesticides remain the first option of most farmers for crop protection. As per some estimates, cotton may account for about 50% of the total 2.254 million t of active ingredient of synthetic chemical pesticides produced globally ([www.fao.org/ES/ESS/sumfas/sumfas\\_en\\_web.pdf](http://www.fao.org/ES/ESS/sumfas/sumfas_en_web.pdf)). Synthetic pesticides are poisons that adversely affect nervous system, respiratory system, endocrine glands or skin. Pesticide-residues in food chain and in the blood of user farmers are important issues widely talked about by NGOs, press and media. This seems due to the fact that though prescribed by researchers and industry, hardly any farmer in a developing country is noted using the suggested precautions. Money spent on chemical pesticides can be 50 % of the total input cost of production in some crops, particularly cotton. We have been looking for ways to reduce this huge cost to farmers, especially for insect-pests that attack important crops like cotton and pigeonpea. After 3 years of managing insect-pests on pigeonpea and cotton, using low-cost and biological options (not organic farming) in a long-term experiment on a one-hectare field at ICRISAT, we ventured to evaluate the best-bet protocol on-farm in 2003/04 crop-season. Farmers in Kothapally, when approached and informed of scope of a partnership experiment on crop-protection, chose to evaluate the protocol on cotton as a test crop. A four-year account of this on-farm experience is given here.

The eco-friendly protocol involved six items, and some small changes in agronomy. The first two were extracts of two botanicals Neem (*Azadirachta indica*) and *Gliricidia sepium* (a leguminous tree), prepared using a biological method (modified) at ICRISAT. The third and fourth are research products of ICRISAT - two microorganisms; i) the bacterium *Bacillus subtilis* strain BCB19, and ii) the fungus *Metarrhizium anisopliae* GVR. The last two components are items that farmers have traditionally used. These are a) cow-urine solution, and b) a curd recipe, that involved specific quantities of curd, jaggery (concentrated sugarcane juice) and bread yeast – all mixed in water and sprayed. As per documents on traditional knowledge of farmers, cow urine serves as a repellent and the curd-recipe as an attractant to friendly insects such as wasps. The curd recipe is applied only once at about 50% flowering stage. In addition, a mixture of three different bacterial strains (a) *Pseudomonas fluorescens* - promotes plant growth, makes insoluble-P soluble and suppresses soil-borne fungi,

(b) *Azotobacter vinelandii* – fixes N<sub>2</sub>, and (c) *Bacillus licheniformis* promotes plant growth; were soil-applied at sowing. Trap crops were also prescribed.

The biological plant-protection protocol was evaluated by 17 farmers in Kothapally village, Andhra Pradesh in 2003/04 season (first year). Each farmer agreed to experiment on a one-acre (1 ha = 2.42 acre) plot, divided into two parts. On one part farmers used chemical pesticides, called farmers' practice (FP) and on the other they used the low-cost materials, indicated above (BIO). From 2004/05, the experiment was extended to village Yellakonda in Andhra Pradesh and village Chaswad in Bharuach district of Gujarat. In the first year, the materials used in the BIO plots was given free of cost to the farmers in all the three villages. It was noted that some farmers did not use the materials when provided for spray, or used inappropriately, ignoring advice of staff visiting the villages once every week. It suggested low importance some farmers gave to the material and advice provided free. Therefore from the second year a charge of Rs. 2400/- (1 US\$ approx. Rs. 45/-) was proposed but farmers agreed to pay Rs. 1700/- per ha. The approach on crop protection and charging, described above, was followed in all the three villages. Different number of farmers participated in different years. Data was collected on pest-damage, population of coccinellids/spiders and yield. Farmers actively participated in data collection. Data from a given village and year was regarded as one batch where each farmer was treated as one replication for the purpose of statistical analyses. From year 2, plot size varied between farmers and treatment, and was determined by farmer.

Mean yield (of all participating farmers in a given village/year/season) of the BIO plots of cotton was generally more by 1 to 30% (Table 9.2.2.7.1) than that of the relevant FP treatment mean (0.94 to 2.66 t ha<sup>-1</sup>). Also, of the 109 sets of BIO versus FP plots where evaluation was conducted in the 4 years, yield in about 77% cases was higher (data not shown), even if marginally, in BIO than FP plots. Thus lower yield in BIO than relevant FP plots was recorded only in the rest 23% cases and was generally associated with lack of understanding and appreciation of the biological approach of crop protection. Irrespective of loss or gain in yield in different years, every farmers spent substantially less on their BIO plots of cotton. Most farmers spent more than Rs 4000/- per ha on the FP plots.

**Table 9.2.2.7.1. On-farm evaluation of biopesticides-based protocols of protecting cotton, 2003/04 to 2006/07.**

| Village/ Season/ Crop    | Mean yield (t ha <sup>-1</sup> ) |      |       |
|--------------------------|----------------------------------|------|-------|
|                          | BIO                              | FP   | SE±   |
| Andhra Pradesh           |                                  |      |       |
| Kothapally 2003/04 -17*  | 2.43                             | 1.87 | 0.080 |
| Kothapally 2004/05 - 10* | 0.95                             | 0.94 | 0.031 |
| Kothapally 2005/06 - 5*  | 1.81                             | 1.40 | 0.110 |
| Kothapally 2006/07 - 9*  | 1.99                             | 1.68 | 0.061 |
| Yellakonda 2004/05 - 21* | 1.15                             | 1.21 | 0.043 |
| Yellakonda 2005/06 -7*   | 1.48                             | 1.29 | 0.055 |
| Yellakonda 2006/07 - 10* | 1.95                             | 1.56 | 0.058 |
| Gujarat                  |                                  |      |       |
| Chaswad 2004/05 -10*     | 1.53                             | 1.43 | 0.034 |
| Chaswad 2005/06 -10*     | 1.47                             | 1.38 | 0.028 |
| Chaswad 2006/07 -10*     | 2.84                             | 2.66 | 0.063 |

\* Number of farmers participating in the experiment in a given season

Population of coccinellids and spiders, indicators of beneficial insects, was generally low but was still higher in BIO than in the FP plots. Cotton plants in the BIO plots generally remained productive for 2 to 3 weeks longer than the FP plots that generally senesced suddenly.

Staying in touch with each farmer was very crucial for the success of the on-going program of on-farm evaluation of the biopesticides-based protocol of managing insect-pests. In the absence of good connectivity,

farmers tended to fall-back on pesticide dealers for advice. There were three occasions in the four years when farmers called us in panic and shared their concern for high population of insects in BIO plots. Upon visit, in one out of the four cases the insect was identified as predator of pests. This strongly suggested that in the absence of synthetic pesticides, natural enemies of insect-pests will bounce-back. Population of predators of insect-pests was invariably higher in BIO than in FP plots. There were several tension-filled occasions, invariably associated with occurrence of insect-pests for which we did not have a trusted biopesticide-based solution. These pests were aphids, thrips, red cotton bug and stinking bugs. Resorting to botanicals generally helped in containing damage. Mixture of cow-urine (10%) and finely powdered five different botanicals (5%) helped in most cases.

All items of spray application used were evaluated in lab conditions before their inclusion in the protocol. The two items of traditional knowledge - cow-urine and curd-recipe did not kill the insect-pests in lab conditions, but neonates and the young larvae did not feed well on leaves of groundnut or on sprouted seeds of chickpea (used as food) sprayed with these products.

It is widely accepted that most biopesticides fail to kill big larvae (4th instar and above) and are generally slow in action. We therefore decided to use them as prophylactic. Biopesticide was sprayed almost every week. This meant up to 15 sprays in the whole cotton season in the case of some farmers. Farmers were critical of the large number of sprays in the BIO plots even through some of them sprayed synthetic chemicals up to 19 times in the FP plots in the first two years. The large number of sprays in the BIO plots were due to factors like (a) the trial sites were almost always surrounded by fields sprayed with synthetic chemicals and on some occasions insect-pests shifted from FP (when sprayed) to BIO plots, (b) farmers generally failed in establishing trap crop due to its incompatibility with the intensive inter-culture afforded to cotton, (c) trees that shelter predators of insect-pest on a farm were generally absent, (d) long use of synthetic pesticides on the different farms perhaps reduced the population of predators to a very low level. It may be noted that for effective management of insect-pests, predators are very important along with biopesticides.

In the crop season 2005/06 most farmers and in 2006/07 all farmers used Bt cotton. This resulted in substantial reduction in the number of sprays in the FP plots. This made the partner farmers further reluctant to accept large number of sprays in the BIO plots. Mean sprays in the FP plots in 2006 was 2.9 to 3.2 and in the BIO plots was 3.7 to 4.1. This indicates a substantial reduction in the number of sprays which generally crossed 10 in most cases in the past when all farmers used non-Bt cotton.

The four years experience strongly suggested that cotton could be protected successfully with low-cost and biological options. The protocol involved using some biopesticides that can be produced in the villages itself by a rural enterprise and thus offered an employment opportunity to rural people. Microbial biopesticides have to be produced by biopesticide companies. Overall, the experiment demonstrated that synthetic pesticides are not essential to protect crops and the alternative means can work. Occasional failures indicated the need for more research on these aspects. The fact that the protocol could be shared and executed successfully by farmers through guidance from field level technical staff, suggests a big scope of its scale-up. Protecting crops of farmers by contract charging, of the type shared in this document, could be a new rural enterprise.

## **Project 10: Virtual Academy for the Semi Arid Tropics in SAT Asia and WCA**

### **Summary**

During the year 2007, activities on this project focused on achieving outputs 10.1.1 and 10.1.2 in the logframe. The outputs were generated as projected. A number of trials in blending of online tools for more effective content organization have been carried out and the results shared with partners. A strategy for knowledge sharing that would build newer linkages in the continuum of research-to-extension has also been developed, discussed with NARES partners, and a research project launched in India in four states (each with a population in excess of 25 million). The project is a direct outcome of outputs 10.1.2 in the logframe.

*MTP Output target 2007 10.1.1: Repository design with one group of objects completed and tested and report shared with partners.*

#### *10.1.1 Design of a Blend of Tools in Knowledge Sharing*

One of the key challenges identified in the previous years of research was the need to develop a content organization that will support a range of information and capacity development services, linking research and education partners in the NARES with a variety of rural organizations and extension support systems. The possibility of contemporary information and communication technology (ICT) derived tools in forming newer and more effective links in extension support has been brought out by a number of extension experts globally in the recent years. We identified a global resource, namely, the FAO's AGROVOC thesaurus as the basis of the new content organization. It would serve as the basis for forming relationships between concepts in nearly every aspect of agriculture; in the parlance of modern information science, the AGROVOC would be the ontological basis of new ways of relating online information objects to one another.

With the AGROVOC as the basis, three different trials were carried out to find the most practical blend of tools for an online content organization. The first trial involved the use of the technology of topic maps, developed over the last few years by the community of semantic web researchers. The purpose of topic maps is to allow for visualisation of conceptual relationships using a map-like interface that allows scaling down into deeper relationships. Topic maps provide a knowledge structure to organize information resources and to associate relationships among them. This facilitates the move from a data model-based repository to a knowledge model-based repository, which is a shift promoted by the World Wide Web Consortium to build what is called the Semantic Web ([www.w3.org](http://www.w3.org)) to support more specific and targeted queries that users in the education and research sector may require. Information objects such as web pages are attached to fine-grained concepts that can be spotted in a topic map. They can be retrieved with limited effort by tracking the conceptual relationships visualized as maps and trees. A tool called Ominigator ([www.ontopia.net](http://www.ontopia.net)), an open source application, was adapted to use AGROVOC as the ontology, and crop-specific topic maps for all the five mandate crops of ICRISAT were developed (<http://test2.icrisat.org>). These maps were linked to the online repository of learning granules maintained in the VASAT web site at <http://vasat.icrisat.org>. The learning materials can be searched and a unique page in the VASAT repository can now be identified either through the tabular representation of AGROVOC relationships specific to a crop, or using a map-like interface that can be enlarged ("zoomed in") or contracted (a zoomed out") to reveal intricate or gross relationships. The maps so constructed can be refined further as new information or learning modules are added. A survey of technical literature showed that this is the first time that topic maps have been applied in the agricultural research and education sector.

In the second trial, a different approach, also rooted in semantic web research, called the semantic Wiki tool, was tried. In this attempt, we made a blend comprising the Wikimedia services online (a Web 2.0 tool), the semantic Wiki software and the AGROVOC thesaurus. We analysed the entries in the English Wikipedia (containing about 2.14 million entries as of December 2007) to identify content that can be termed pertaining to agriculture (just under 2000 entries, a proportion of less than 1% of entries in the English Wikipedia). They were downloaded into a local repository and were transformed into granules that are tagged with AGROVOC terms. Once so tagged, the semantic Wiki tool was applied to create interrelationships between disparate entries. New relationships that were not transparent in the Wikipedia can now be identified. The trial repository with about 1000 entries is available at <http://vasatwiki.icrisat.org>.

In the third trial, the VASAT learning modules were downloaded into a Wikimedia server to create a trial repository, and the AGROVOC terms were applied and the semantic tool was applied on the crop-related

modules. New relationships between various learning granules became transparent as a result of this operation (also found at <http://vasastwiki.icrisat.org>). A trial repository of re-usable learning objects (RLO's) has thus been created.

Based on the analysis of the trial results, we realized that a tool to combine user-selected information or learning granules was necessary, so that users can create their own content that is directly derived from peer reviewed online content. Comparison of documented experiences in the technical literature showed that a tool called eXe ([www.exelearn.org](http://www.exelearn.org)), developed in New Zealand and disseminated by the Commonwealth of Learning ([www.col.org](http://www.col.org)) was most suitable and practical for this purpose. A series of experiments were conducted in using this software to combine learning modules identified in the VASATWiki service, to create user's own content. The results showed that eXe indeed suited the purpose.

The results and recommendations from this series of studies were presented in a peer-reviewed international conference called Web 2.0 for Development, organized by a consortium organizations that included the FAO, GFAR and the CGIAR ICT-KM program ([www.web2fordev.net](http://www.web2fordev.net)). A modified version was also presented at the World AgInfo workshop organized at the Cornell University in October 2007 ([www.worldaginfo.org](http://www.worldaginfo.org)). The partner responses indicated that the Wikipedia route should be more widely tested for adoption, in extension as well as in education. A shorter version while at the development stage was also presented at the E-learning Africa (May 2007) through the Commonwealth of Learning forum associated with this event.

*MTP Output target 2007 10.2.1: Two capacity strengthening workshops on localization undertaken with two partners and reports published*

#### *10.1.2 Strengthening Knowledge Flows to Facilitate Ease of Access to IPG's by Partners*

During this year, we focused on building new approaches to rendering institutionally generated knowledge into re-usable learning objects, to allow partners to adapt them for local use. The learning objects approach began to be widely used in higher education and is today an accepted practice in the design of learning material repositories. Major international efforts such as those of UNESCO (Open Educational Resources), UNEP (Mentor) or the Rice University (Connexions- <http://cnx.org>) have adopted this approach to design learning materials for use globally by any partner.

ICRISAT and the University of Florida developed a joint proposal for the design of learning objects for use by NARES partners in education and extension, and have organized a year-long program of activities in strengthening the capacity of agricultural university partners. The activities involve both creation and re-use of learning objects. In the current phase, water management has been chosen as the focal area. Initial support for this program came from the joint US-India Agricultural Knowledge Initiative while the Commonwealth of Learning joined in to support specific capacity development activities in the area of extension-oriented learning objects development. A workshop organized in India (March 2007) under this initiative had five Indian agricultural universities participating in it. The objectives of the workshop included identification of needs and topical materials for e-materials development in the form of RLO's, and to analyse available experiences in outreach using e-materials. A total of 48 experts in water management and extension participated in the workshop which also considered the opportunities to use at least some RLOs in distance learning in water management (project web site at <http://akicb.ifas.ufl.edu/>). A priority list of topics has been developed, the technological specifications finalized and sample RLOs have been developed. A four week long workshop in U Florida in February 2008 has been scheduled to finalise the RLOs in different levels of development and participants selected from the participating universities will finalise these and publish them.

ICRISAT also organized a workshop (April 2007) to consider options to build capacity among NARES partners in the use of tested and available technologies to build a comprehensive content organization to reach out research-derived IPGs to extension and education sectors. Seven national partner organizations in India attended the workshop which was entirely funded by the ICAR ([www.naip.icar.org.in](http://www.naip.icar.org.in)). Three of these were ICT resource institutions with significant interest in the agricultural sector. ICRISAT proposed the possibility of an integrated content organization that can combine a variety of content production methods involving international and national partners with an open architecture for the rapid and relevant localization and delivery of content in multiple modes involving digital or non-digital delivery methods. The partners agreed to develop such an architecture which was developed through a series of consultations in the first half of 2007. It has now been funded as a research project by the National Agricultural Innovation Project of ICAR, with the Wiki-based content organization at its core, an advanced data-mining-based online forum to enable expert-expert, expert-

extension worker, expert-farmer interactions and a multi-modal delivery system based on open services architecture (not limited to Internet) involving mobile telephone devices as principal access devices for information alongside PC's and radio. The NARES partners have accepted the use of AGROVOC as the ontological basis and it is already rendered into two Indian languages, pending official (State Government) approval. (The Hindi version has already been linked to the FAO's AGROVOC database ([http://www.fao.org/aims/ag\\_intro.htm](http://www.fao.org/aims/ag_intro.htm)) by the Indian Institute of Technology, Kanpur, which partners with ICRISAT in building the new online content organization). The project has been launched in December 2007.

Hard copies of both workshop documents were made available to participants and see also:

<http://akicb.ifas.ufl.edu/proceedings.asp>

#### *Auxiliary Activities Contributing to the Logframe Outputs:*

Three streams of activities have contributed to the core activities on this project. The first stream is the large scale digitization and open archiving process in ICRISAT that makes it possible to create re-usable digital objects on a large scale. The second group of activities involves experiments in technology-mediated rural communication while the third group relates to capacity development and curricular design programs with Open Universities.

#### *Large Scale Digitization and Setting up of Open Institutional Archives:*

During the year 2007, ICRISAT commenced activities in association with the globally managed Million Books Project (<http://www.ulib.org/>) to digitise its publications since inception. As of the end of the year, about 40,000 pages have been scanned and digitized and about 60 % of these scanned pages have been converted into the searchable PDF that can be indexed by major online search engines.

This important resource is made available using the protocols followed in the design of institutional open archives ([www.openarchives.org](http://www.openarchives.org)). All these are now freely available to the public who can avail of a low bandwidth internet connection. In addition, copyright-free research publications that appeared in peer reviewed journals or were presented in peer-reviewed conferences have also been digitized. Out of estimated 2400 such institutional publications, 650 publications have been added to the archives as of December 2007, to provide a test volume to the audit system at the Openarchives.org. Audit completed in December 2007 was successful, clearing the way to add more in 2008. This important auxiliary activity makes it easy for any organization or individual anywhere to access ICRISAT-produced information IPGs through well known scholarly information search services online.

ICRISAT also collaborated with the FAO in development of online utilities for improving the structural and lexical consistency of the AGROVOC as it is premised as the ontological basis for a novel online content organization in agriculture. A number of software codes have been supplied to the FAO and the collaboration continues in 2008.

#### *Experiments in Rendering Extension Support using ICT-Mediated Methods*

In order to generate a coherent design for information access for extension support, we carried out two groups of experiments, one involving the use of internet-connected PCs and another on the effectiveness of use of two-way video conferencing (VC). The overall objective of these studies was to understand the need and role for locally trained individuals to act as facilitators of the processes by which community-based organizations would use PC-based or online information of relevance. The absorption or uptake of information as evidenced in changes in specific local practices was also documented.

The study with PCs was carried out in India with the participation of faculty and research scholars from Stanford University and the University of Amsterdam. The experiments were designed to test the changes in the way farmers actually prepared samples for a soil test and the number of samples delivered for testing. Preliminary results showed that the farmers were able to absorb new information better when the prominence of facilitators and the PC was balanced. Prominence of one over the other resulted in relatively reduced absorption of information. This study is still in a preliminary stage and will be continued in order to generate large volume of data for statistical analysis. One significant off shoot of the study was the transformation of the ICRISAT-designed soil science literacy modules into a form richer in graphics and interactivity, with more local information which was carried out with the help of the rural facilitators.

We conducted a series of experiments on the effectiveness of video conferencing as an extension support arrangement, using satellite-video connected rural resource centers in three different states of India. This was

carried out jointly with the Swaminathan Research Foundation ([www.mssrf.org](http://www.mssrf.org)) and the Indian Institute of Technology, Bombay ([www.iitb.ac.in](http://www.iitb.ac.in)), with the satellite links provided by the Indian Space Research Organization. A number of individual experts from the ICAR joined the experiments to provide solutions to farmers' queries. The experiments started with direct interactions between experts and farmers in different locations connected via the VC. After over six sessions of two hours duration each, it emerged that both the experts and the farmers were finding the interactions not as effective as they were projected. In the second set of sessions, well-trained local center managers were brought on to facilitate queries and to supplement these with useful local information on weather, the seed types, soil data, etc. With this, the satisfaction levels with expert responses appeared to improve as measured among the farmers participating. An additional step was added to introduce the farmer queries into an online forum ([www.aaqua.org](http://www.aaqua.org)) which is used by subject matter specialists in the ICAR extension system. Over a period of three months of regular uploads, a number of expert responses have appeared from a different region in India (also part of the SAT in India). The local resource center managers have been able to use these responses as well in providing a comprehensive set of practical statements of advice to the farmers. Attempts are now on to deliver solutions from this online forum directly to the farmers or the local centers using the mobile-telephony-based messaging services. It emerges that multiple modes of interaction and credible facilitation are important in improving the effectiveness of communication with the farmers.

As part of the extension communication studies, we developed a set of scenarios of seasonal rainfall-based drought-vulnerability maps at a micro-scale (covering an area just under 25,000 hectares, or 11 hamlets) in the study area. Satellite imagery derived from the INSAT series for five years from 1997 was used to construct a detailed map of surface water resources and their status, and these were overlaid with water uses for various activities including crop and livestock production. The threshold rainfall needed to sustain minimal activities was calculated and various scenarios based on rainfall data for the past 25 years were developed. These were presented in grades of three colors indicating scenario variations from extreme stress to business-as-usual. These were presented to the rural facilitators and community-based volunteers who in turn monitored their utility through a season in 2007. The initial results are positive and the acceptance among potentially vulnerable communities is good. The trials will be conducted in 2008 and a strategy for wider use will be developed.

#### **Activities in support of the CGIAR Global Open Food and Agriculture University (GOFAU) Project**

During the year, we proposed the possibility of using the re-usable learning objects approach, coming into wider practice in open learning, as a key component of the materials development and curricular design processes taking place under the umbrella of the GOFAU ([www.openaguniversity.cgiar.org](http://www.openaguniversity.cgiar.org)). This proposal was presented to the relevant committee of the GOFAU and was subsequently presented to partners universities in South and Southeast Asia (workshops and meetings held in January and July 2007). The response from the universities was positive. The RLOs can be built even if online methods are not used or the capacity of faculty members was not sufficient to use such methods. Based on this set of responses, a trial curriculum for an agro-ecology program that the Universities can adapt in offering masters' courses was developed, comprising sixteen course modules that can be constructed from about 1000 sub units and 200 units. The contributions by globally renowned experts can take place at the level of units or sub units. An online collaboration built on the successful practices of read/write interfaces on the web (exemplified in the Wikipedia and a number of similar services) has been proposed. This approach was endorsed in a global consultation with 30 university partners (organized by the GOFAU along with the Bill and Melinda Gates Foundation in November 2007) and a prototype is in design as of December 2007, to be readied for release in April 2008. This is a direct outcome of activities and outputs of component 10.1.1 above.





## About ICRISAT®



The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Centers of the Consultative Group on International Agricultural Research (CGIAR).

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