ICRISAT
Archival Report 2006

The seedlings of success in the semi-arid tropics nurtured

International Crops Research Institute for the Semi-Arid Tropics

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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 by 2009 with new knowledge shared with partners

MTP Output Target 2006: Innovative approaches for generation and utilization of new agricultural technologies and for facilitating innovation identified and piloted

1A.1. Guidelines prepared for the design and operation of efficient community seed production schemes by 2006.

Regional seed policy harmonization (SSA)

Seed policy harmonization has been cited as a means to increase seed trade and reduce seed costs in southern Africa for the past 15 years. However, little have been achieved over this period except the principled agreement that harmonization would be useful. There are three initiatives working towards harmonized seed trade in sub-Saharan Africa:

- Southern Africa: The initiative facilitated by the Southern Africa Development Community - Seed Security Network (SSSN),
- Eastern and central Africa: The initiative facilitated by the Association for Strengthening Agricultural Research in Eastern and Central Africa coordinated by the Eastern and Central Africa Programme for Agricultural Policy Analysis (ASARECA/ECAPAPA), and
- West Africa: The initiative facilitated through the collaboration between the Institut du Sahel (CILSS/INSAH), the West Africa Economic and Monetary Union (WAEMU), and the Economic Community of West African States (ECOWAS) in West Africa.

Although there has been effective intra-regional dialog between countries and in the case of West Africa between the three separate seed trade harmonization initiatives in that region, there has been very limited inter-regional dialog. This will limit seed trade between regions unless there is harmonization across the regions, and this is particularly important between the SADC block and countries in Eastern and Central Africa where there is already some seed trade and potential for a lot more.

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, but to date these have been elusive because there has been limited effort to have the draft technical agreements politically approved. ICRISAT facilitated a linkage with the Seed Science Center of Iowa State University and the SADC Seed Security Network (SSSN) to establish a practical foundation for three regional regulatory harmonization agreements.

In April 2005 and again in August 2006 ICRISAT - in partnership with the African Seed Trade Association (AFSTA) - organized an inter-regional workshop to share experiences across the three initiatives, and to identify areas requiring further support.

Objectives: Work with SADC and other African countries to complete harmonization agreements on:

- seed phytosanitary standards
- seed certification standards
- regional variety release

Methodology: During the past two years, more than 10 workshops have been held bringing together public and private seed sector stakeholders from all 14 SADC countries to hammer out agreements on phytosanitary standards, certification standards, regional variety release and plant variety protection. This was supported by Africa wide efforts for a similar harmonization process in other sub-regions.

Main findings & policy implications: In September 2006, the Permanent Secretaries of Agriculture for the 14 countries of the Southern African Development Community (SADC) endorsed three major regional agreements for the harmonization of seed regulations in southern Africa. A Memorandum of Understanding is now being prepared by SADC to facilitate approval by the Heads of State.

Southern Africa will be the first African region to establish a Regional Variety Release System. This enables the development of a truly regional seed market by allowing any non-GMO plant variety released in at least two SADC countries to be sold in any other country in the region. Seed companies no longer have to pursue the time and budget consuming process of separate variety releases in each of the 14 SADC countries. This agreement will speed access of farmers to the best new varieties in southern Africa. And the agreement will help seed companies pursue scale economies in their regional breeding and marketing programs.

The second harmonization agreement establishes a common Seed Certification and Quality Assurance System. This defines common field and laboratory seed standards for the 13 most traded seed crops in southern Africa. In order to facilitate the implementation of this agreement, accreditation schemes have been created for each SADC member state based on detailed procedures manuals. Accreditation allows seed companies to conduct their own field inspections, sampling and testing, thus reducing the costs of regulatory inspections. Quality assurance manuals are being drafted for a range of smaller seed companies in order to help them quality for accreditation and assure the quality of seed they are producing.

The third harmonization agreement establishes a common Seed Quarantine and Phytosanitary System. This creates a new set of regional quarantine lists governing seed trade within the SADC region, and between SADC and countries outside the region. In the process, the number of quarantinable pests and diseases has been significantly reduced. This program has also helped each of the fourteen SADC countries develop their own seed import and export procedures manuals – based on common procedural standards. Again, this will contribute to reducing the costs of seed trade, while minimizing the risks of trans-border movement of seed transmitted crop diseases.

In addition, the Permanent Secretaries concurred that establishing common legislation governing Plant Breeder's Rights in all SADC countries would promote greater investment in crop breeding and speed the development and trade of better varieties. The Permanent Secretaries received a draft of a regional agreement for the Protection of New Varieties of Plants in the SADC Region, which has been proposed as a basis for each country's national legislation.

These agreements serve as an example for related efforts in eastern Africa and western Africa. ICRISAT is facilitating coordinated discussions about these harmonization efforts across the three African regions.

An important finding from the seed policy harmonization process in Africa is that not all initiatives have been linked to the political process at the level of regional economic communities, and hence getting political approval has been impossible. In addition, lack of technical capacity in some regions meant that technical agreements are incomplete and would be of little benefit even if implemented. This has contributed to the slow progress in other regions. The new initiative under the project for Sustainable Commercialization of Seeds in Africa (SCOSA) has aimed to address this problem by pursuing a strategy that adds value to the ongoing initiatives through cross-fertilization of ideas and existing agreements between regions, and to provide targeted technical support. AFSTA with support from SCOSA has also started engaging with regional economic communities and political bodies including the NEPAD/CAADP to obtain the necessary political support to have these agreements approved and implemented. SCOSA is addressing the following issues:

1. Developing a web-based template for the regional variety catalogs that are needed to support the regional variety release systems being developed in all three regions
2. Contribute to the development/refining of technical agreements including the adaptation of technical manuals on seed import-export regulations and quarantine pest lists, biosafety testing procedures based on process management, regional variety release.
3. Facilitate the development of institutional arrangements and partnerships for improving seed systems through enhanced availability of breeder and foundation seeds and business development services for seed enterprises.

Presently 21 countries across sub-Saharan Africa are in the process of developing business plans for the establishment of Seed Enterprise Enhancement and Development Services (SEEDS) that are expected to produce and market foundation seed of publicly developed varieties, provide storage and processing facilities to seed entrepreneurs as well as technical support, seed certification (where accreditation is feasible) and business development services. This work is being done in partnership with AFSTA, which has the mandate to support the development of commercial seed trade on the continent. Business plans are expected to be finalized by the end of 2006 and efforts are underway to use these business plans to solicit resources to establish SEEDS.

This initiative recognizes the key role of the private sector. The public sector is important in creating an enabling environment. From time to time, consultations are made with the private sector through meetings to determine whether the initiatives being undertaken are facilitating the private sector to participate more effectively in fostering a vibrant seed sector. This is in effect business not as usual because in the past, the public sector was the leader but no longer.

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 by 2009 with new knowledge shared with partners.

Output Target 2006: Data on SAT agriculture developed for NARES and regional/global organizations for prioritization, monitoring and evaluation and technology forecasting generated

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

ICRISAT is maintaining 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). The database available with ICRISAT for 13 states in India was updated in 2001 up to 1997-98 for all the variables in the file and expanded to include data for 3 more states i.e., from 13 to 16 states.

Background: Update of the database is essential to address issues at the aggregate or regional level. State level data are not suitable since states were created on linguistic and political grounds and are not homogenous in terms of agro-climatic and socioeconomic environment. 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.

Progress**:** In 2006 the database is being updated until 2004 for all the districts in the 19 states in the dataset. Updating the database is a herculean task involving travel to state Directorates of Economics and Statistics, Directorates of Agriculture, Marketing Departments, Animal Husbandry, etc located in each state capital for collection of data from published and unpublished sources. This was accomplished to a large extent for key variables in collaboration with CRIDA an ICAR institution that are partners in the update of the dataset. Data from only a couple of newly formed states is still in the process of being collected. To bring the data to usable form, coding, checking and inputting, processing and merging with existing database, and finally making the database compatible with GIS for spatial analysis etc are in progress and will continue in the first quarter of 2007.

Handling new districts: 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 had to be worked through, to accommodate both the need for continuity over a long–term, and the need for conducting spatial analysis (or operationalzing GIS) using the most recent data.

Since it is not possible to update the database by a single agency presently, we are updating the database in collaboration with CRIDA, Hyderabad, under the ICAR-ICRISAT collaborative projects. ILRI and IWMI are also collaborating in the update.

1B.2. Coordinated impact database development in Asia and WCA

<u>Training on impact assessment for agricultural technologies (Global)</u>

Research evaluation and impact assessment work is carried out in close partnership with the national programs and other partners. This is facilitated through training modules for capacity building and skill development. The earlier development of training modules on research evaluation and impact assessment was a collaborative project between ICRISAT and the Australian Centre for International Agricultural Research (ACIAR). Additional modules were based on ICRISAT's 'Training program on research evaluation and impact assessment (REIA)' conducted for various countries in Africa and Asia. More modules were added during the 'Training workshop on impact assessment' held at Kasetsart University, Bangkok, Thailand. Another training workshop on 'Impact assessment of agricultural technologies in West Africa' in 2005 included new modules and case studies (Ndjeunga et al., 2006). French versions of all modules were presented to the participants of this workshop.

The modules completed include basic methodology, empirical issues, research evaluation, minimum data sets, research costs in project-level evaluations, cost analysis, adoption, research lags, probability of success, research spillovers, new products, supply-shift assumptions, validity of claims on impact and other methodological issues. Hands-on exercises using research evaluation models have also been developed and piloted in several workshops held in Asia and Africa. The completion of the training manual for impact assessment is important particularly in strengthening the capacity of NARS partners to conduct impact assessment studies. This facilitates the technical backstop function of ICRISAT as it seeks to undertake joint impact studies with national program partners.

The last training in West and Central Africa involved sixteen participants from ICRISAT and the national programs in Burkina Faso, Mali, Niger, Nigeria and Senegal. It primarily covered country studies for assessing impacts of groundnut, sorghum and millet technologies as well as natural resource management. This is a joint activity with GT-CI, under the Groundnut Seed Project (GSP). National program representatives identified specific jointly-developed technologies that should be targeted for impact assessment. The training manual adapted the earlier modules developed in Asia and produced a technical manual for future use in a publication entitled, "Impact Assessment of Agricultural Technologies in West Africa: Summary Proceedings of a Training Workshop on Impact Assessment: Technical Notes & Exercises".

1B.3. Vision for SAT research to 2015 - Analysis of strengths, weaknesses, challenges, opportunities and threats

The overarching goal of ICRISAT has been to provide custodianship to six mandate crops and improve germplasm, and options for the diversification of SAT farming systems that will contribute to development policies of national sub-regional institutions and donors aimed at meeting the Millennium Development Goals. The core value is to improve wellbeing of the poor of the semi-arid tropics through agricultural research for impact. Through extensive discussions and information gathering, a framework for analyzing ICRISAT's strengths and weaknesses was developed to guide the process of formulating a core value and strategy of ICRISAT to 2015. The inventory of ICRISAT's internal strengths and opportunities (as well as areas for improving identified weaknesses) explored directions and implications of future R&D. Wide-ranging regionally oriented bottom up in-house planning exercise and interactions with stakeholders identified pressing issues both in research and research management. An open-ended SCOT questionnaire format gave opportunities to gain feedback from scientists, managers and stakeholders and to explore and analyze the recent changes in the international research environment, as well as current environmental, socio-economic-political situation (especially those affecting agricultural research) and trends. It also paved a way to figure out the trends associated with identified scenarios to strengthen our strategic and tactical decision-making.

Collaborating Scientists:
All scientists from all global themes, units and regions, ICRISAT.

Report on impact assessment of sorghum and millet research in West and Central Africa: A synthesis and lessons learnt

Rationale: In a time of increasing scrutiny about the usefulness of investments in agricultural research, impact assessment studies assist to demonstrate the value of continued investments in research. Lessons learnt from impact assessments can be used to improve future research strategies, plans and management. This paper reviews and synthesizes the findings of various studies on the adoption and impact of sorghum and millet technologies research in West and Central Africa (WCA).

Methodology: The review covers Burkina Faso, Cameroon, Chad, Mali, Nigeria and Niger where relatively more breeding research has been conducted. The information is mainly drawn from studies on the diffusion and impacts of varieties carried out by ICRISAT and National Agricultural Research Systems (NARS) of WCA.

Results: Findings from reviewed studies show that returns to research (and diffusion) investments are quite high, but the performance varies across countries. However, if improved technology is to make a meaningful impact at the farm level, it must be accompanied by at least three complementary factors: 1) an effective extension service; 2) an efficient input distribution system, and (3) appropriate economic incentives. These results are essential for priority setting of research and development interventions.

Impact assessment of sorghum and pearl millet varieties in Northern Nigeria (WCA)

Rationale: Nigeria is ranked first in terms of pearl millet and sorghum production in West Africa. It accounts for about 50% of total sorghum or pearl millet production. However, productivity of these crops that are essential to ensure food security for smallholder farmers in the Sahel is still low. Since 1990, ICRISAT in partnership with IAR developed a large range of pearl millet and sorghum varieties and hybrids that are preferred by farmers and some of these varieties have the traits required by the markets. However, little is known about the level and extent of the level of adoption of these improved varieties and constraints to adoption. As the first step, this study evaluates the adoption of sorghum and millet varieties in selected states in Northern Nigeria.

Methodology: Six states (Borno, Jigawa, Gombe Kaduna, Kano and Katsina) in northern Nigeria were selected based on the relative importance of sorghum and millet. Following a PRA, a structured survey was carried out covering 840 small-scale farmers. The varieties investigated include ICSV400, ICSV111, SK5912, ICSH89002NG, ICSH89009NG, NSSH91001 and NSSH91002 for sorghum cultivars and SOSAT-C88, GB8735, EX BORNO, LCIC9702, LCIC9703, ICMV-IS89305 and GWAGWA for millet cultivars.

Results: Adoption survey results showed that yields from improved varieties are significantly higher than the local landraces. The average yield for improved pearl millet varieties is estimated to about 1126 kg per hectare against about 940 kg/ha for the local for the period 2003-2005. This represents a yield advantage of about 20%. As for sorghum, the productivity gains are estimated to about 31% (1324 kg per hectare for improved cultivars and 1011 kg for local varieties). The gains are realized from the reduced productivity loss as a result of drought and disease resistance of improved varieties. Kano State enjoyed the highest yield increase (43%) for sorghum whereas the mean yield (1474 kg per hectare) from improved millet cultivars was highest in Borno State.

The overall rates of farmers growing improved sorghum varieties were estimated to 78% for ICSV400, 66% for ICSV 111, 92% for SK5912 and 66% for KSV8. Concerning improved millet varieties, the rates of awareness were 91% for Ex-Borno, 76% for SOSAT-C88 and 67% for GB8735. On average, about 56 % (1.28 ha) of the total area under sorghum in 2004/05 was planted with improved sorghum and 47% (1.07 ha) of the total area under was planted with improved millet varieties. These represented increases of 21% (1.05 ha) for sorghum areas and 30% (0.82 ha) for millet areas relative to the preceding 2003/04 cropping year. It is worth noting that of all the cultivars investigated; ICSV 400 and SOSAT-C88 have the highest proportions of cultivated allocated them. They were respectively 47% and 31%.

The most important drivers for adoption of improved sorghum varieties were different from the ones cited for adopting improved millet varieties. For sorghum, high yield was ranked first followed by early maturity, selling price, storage ability, food quality and drought/disease resistance. For millet, early maturity ranked first, followed by high yield, food quality, selling price and drought/disease resistance. The high ranking of early maturity trait is a confirmation that drought is the major constraint to pearl millet production in northeastern part of Nigeria. In effect, most farmers are small-scale and semi-subsistence farmers whose major goal is to ensure food security for their families. Early maturing cultivars provide an early end to the annual hunger period (June's first rain to September's first harvest). The high ranking of the high yield trait for sorghum can be explained by the fact in Kano and Kaduna, sorghum competes with high yielding crops such as maize.

Early adoption of groundnut varieties in Northern Nigeria (WCA)

Rationale: Nigeria is the 4th largest groundnut producer in the world and the first in West Africa. Groundnut averages 2,730,000 t in 1997-2001 accounting for about 9% of world production and 34% of Africa production. Nigeria has lost its production share with 11.87% of production share in 1961-65 to 8.51% in 1997-01. Despite this loss, groundnut remains the most important source of vegetable oils and fats in West Africa. Groundnut production has suffered major setbacks from the rosette virus that significantly affected productivity. This led Nigeria to lose its shares in the international and regional markets. To regain its shares, groundnut yield would have to increase substantially, using yield enhancing technologies including varieties tolerant or resistant to rosette.

Since 1990, ICRISAT and IAR have developed, tested or adapted 44 groundnut varieties. These varieties were tested in multi-locational trials in partnership with ADPs and NGOs in the regions of Samaru, Bagauda, Minjibir, Shika, Kano, Katsina and Maiduguri. In 2001, 3 groundnut varieties (SAMNUT 21; SAMNUT 22 and SAMNUT 23) were released. Since then, there is limited knowledge on the level of use of these varieties. This study assesses the diffusion and preferences of farmers for varieties recently released in 2001. Information on other improved varieties is also available.

Methodology: A structured survey was conducted in 4 northern states of Nigeria mainly Kano, Jigawa, Katsina and Kaduna in December 2004. These states account for more than 70% of groundnut production in the Sahelian zone of Nigeria. Three groundnut varieties (SAMNUT 21, SAMNUT 22 and SAMNUT 23) were targeted for the study. Eleven local government areas were purposely selected on the basis of the importance of groundnut production. In each LGA, 2 villages were on the same basis and in each village, a random sample of 25 farmers was chosen. Therefore, a total of 480 farmers were interviewed.

Results: Survey results show that 12.13% of groundnut area is planted with improved varieties , ie. SAMNUT 21 accounting for 7.20%, SAMNUT 22 for 3.07% and SAMNUT 23 for 1.85%. Other varieties were reported to be grown as well. These include the varieties 55-437 on 12.23% of area planted, 12.26% for RMP 12, 2.69% for RMP 91 and 7.80% for RRB. The major constraints limiting the adoption of modern released varieties include the poor access and availability of seed and lack of information. Other minor constraints are low yield, susceptibility to diseases and pests, and poor market value.

Assessing diffusion of pearl millet varieties in Niger (WCA)

Rationale: From 2002-04, ICRISAT initiated a large multi-locational pearl millet participatory variety selection trial in Niger with major objective to evaluate performance of new varieties on farmers' fields, identify farmers' preferences on varietal traits, as well as identify production and adoption constraints. Following the introduction of pearl millet varieties little is known on the adoption of these varieties. This study assesses the levels of adoption and factors affecting farmers' adoption decision, and formulates ways in which research, extension, and policy could improve their adoption.

Methodology and data: A study was initiated in two major millet growing regions of Niger, namely Dosso and Maradi. Data were collected from primary and secondary sources in the departments of Aguie, Madarounfa and Dogon-Doutchi were the trials were implemented. Secondary sources included published and unpublished information about agricultural production in particular and the study area in general. The survey was conducted in April 2005 and it involved farmers who had participated in PVS on-farm trials and demonstrations during 2000/2001 to 2002/2003 cropping seasons. A total of 300 households were interviewed from 13 villages.

Results: The major improved pearl millet varieties grown in the study areas include SOSAT-C88, HKP, P3KOLLO, ZATIB and CIVT. The area covered by improved varieties is estimated to 15% (0.57ha / production unit). The main sources of information about improved varieties vary across locations. In Doutchi, most farmers (60%) have been linked to NGOs (CRS and CARE), 20% to a seed center and 20% to the "Projet de Gestion des Ressources Naturelles" (PGRN). In Madarounfa and Aguie (the Maradi region) INRAN dominates (around 85% of farmers reported so) as the main source information about improved millet varieties. This could be explained by the strong presence of INRAN in Maradi.

Farmers' rating of the different criteria varied across the study sites. High yielding, early maturing and ability of a variety to perform well under low soil fertility, and drought conditions were reported as the choice criteria in all sites. The factor limiting adoption include low soil fertility, lack of financial resources to purchase inputs and high prices of the inputs (especially fertilizers and seed), and low technical know-how. Other constraints enumerated are pests and diseases, vagaries of weather, unavailability of inputs, poor access to agricultural extension services, and poor marketing of both inputs and outputs. Farmers also ranked highly markets access (i.e. distance to the Nigerian border), information and unreliable rainfall as key constraints because they believed that alleviation of these constraints would lead to alleviation of many other constraints.

<u>Impacts of inventory credit, input supply shops and fertilizer microdosing in the drylands of Niger (WCA)</u>

This study investigates the impacts of access to inventory credit (*warrantage*), input supply shops, fertilizer micro-dosing demonstrations, and other factors on farmers' use of inorganic and organic fertilizer in Niger, and the impacts on crop yields. We find that access to warrantage and input shops and participation in fertilizer micro-dosing demonstrations have increased use of inorganic fertilizer. Access to off-farm employment and ownership of traction animals also contribute to use of inorganic fertilizer. Use of organic fertilizer is less affected by these factors, but is substantially affected by the household's crop mix, access to the plot, ownership of durable assets, labor and land endowments, and participation in farmers' associations. Land tenure influences both inorganic and organic inputs, with less of both on sharecropped and encroached plots.

Inorganic fertilizer has a positive impact on millet yields, with an estimated marginal value-cost ratio greater than 3, indicating significant profitability. Organic fertilizer has a positive impact on millet-cowpea yields. We find little evidence of complementarity between inorganic and organic fertilizer. Since warrantage (inventory credit scheme), input supply shops and fertilizer micro-dosing demonstrations increase use of inorganic fertilizer which in turn increases millet yields, these interventions indirectly increase millet yields, although the impacts are relatively small. These findings support promoting increased input use through promotion of inventory credit, input supply shops and fertilizer micro-dosing demonstrations. Other interventions that could help to boost productivity include promotion of improved access to farm equipment and traction animals and improved access to land under secure tenure.

1B.5. Report on impact assessment of soil and water conservation methods in Burkina Faso completed (WCA)

<u>Rationale:</u> Substantial progress has been made in the development, testing and dissemination of potentially profitable technologies for improved soil and water management in West Africa. There is growing evidence that some of these technologies (e.g. rock lines, branch barriers, small dikes, vegetative bands, compost pits) are beginning to be widely adopted. However, the full extent of this adoption remains uncertain. There have been no systematic efforts to evaluate the degree or quality of adoption (i.e., correct use of techniques). Little is known about how many farmers are adopting these technologies, and there are no known attempts to record the extent of dis-adoption over time (e.g. when the special development project ends).

Past research by ICRISAT has raised a range of hypotheses about the levels and determinants of the adoption of soil and water management technologies in West Africa. Few studies on adoption of soil and water conservation technologies have been conducted. This study aims at analyzing the levels and determinants of adoption of soil and water management (SWM) technologies and evaluates the impacts of SWM/fertilizer adoption on productivity, incomes, and the environment and the determinants of adoption.

<u>Methodology:</u> Data collection on impacts of soil and water conservation methods in Burkina Faso completed. A PRA was undertaken with the main objective to gather relevant information on soil and water conservation technologies practiced by farmers in Northern Plateau of Burkina Faso, determine the incentives and motivations to use these technologies; pre-assess the impacts and pre-identified the constraints to uptake of these technologies. PRA tools were used to gather information from key resource persons from 2 contrasting villages: Ziga in Yatenga province and Rissiam in Bam province.

PRA results show that stone bunds and zaï were the most widely used technologies in Ziga village whereas, stone bunds, small dikes, and dikes were the most widely used technologies practiced by farmers in Rissiam. Farmers often used more than one conservation technology to maximize benefits from conservation structures. According to farmers' groups interviewed, there have been impacts due to the use of these technologies and translated by land recoveries, regeneration of land cover, increase in the water table, improvement of households' production and revenues and population fixation. However, constraints to adoption have been reported as insufficient labor, lack of organic manure, lack of equipment and plants.

This PRA was followed by a structured survey in the North, centre-north and centre regions of Burkina Faso. In each region, 7 villages were selected on the basis on population densities, and market access and relative assessment of uptake. In each village, 1 village with high adoption, 2 with average adoption, 2 with low adoption and 2 control villages were purposely selected. In each village, on average 15 households were randomly selected. Therefore a total of 405 households were interviewed. Four questionnaires were developed to gather information at (1) village level, (2) project level, (3) household and plot levels, and (4) research and extension costs. Information will be used to assess impact using the economic surplus and the econometric models.

Results: Preliminary results indicate that farmers are well aware of NRM technologies such as the stone bunds (81%), zaï (65%), manure pits (61%), sowing in line (60%). But they are less aware of half moon (9%), vegetative bands (15%), compost (26%) or small dikes (3%). The main information sources are rural development projects and NGOs involved in soil and water conservation (62%), other farmers (41%), and the traditional extension services (39%). Minor sources include research institutions (8%), radios and television (4%).

The proportion of surveyed farmers reporting using stone bunds is estimated to 70%, 50% for the zaï, 5% for half- moon, 4% for vegetative bands, 21.5% for compost and 12% for rotation. Constraints to dis-adoption of these technologies reported by farmers include the lack of agricultural equipment (60.3%), lack of labor (13.2%), low yield (8.8%), poor training (7.4%), and poor access to inputs. Farmers claimed that the reasons why they are continuing to use or maintain the technologies is because they derive high productivity gains (80%), or they are linked to rural development projects that provide equipment or food for work (55%) or they have access to agricultural equipment (45%).

1B.6. Other NRM impacts

Stochastic dominance analysis of soil fertility restoration options on sandy sahelian soils in Southwest Niger (WCA)

The poor fertility of sandy Sahelian soils remains one of the major constraints to pearl millet (Pennisetum glaucum) production in West Africa. On-farm trials under farmers' management were conducted in two rainfall zones of Niger in 1996 and 1997 to evaluate the risk characteristics of six soil fertility restoration options. Stochastic dominance analysis was used to compare the fertilizer treatments tested. Results showed that the farmers' traditional method (no fertilizer control), Tahoua phosphate rock (PRT) alone applied at 13 kg P ha^{-1} broadcast, and a combination of PRT broadcast at 13 kg P ha^{-1} and single super phosphate (SSP) hill-placed at 4 kg P ha^{-1} had the most desirable risk characteristics and were acceptable to risk averse decision-makers in both rainfall zones. At current input–output price ratios, most fertilizer-using farmers would choose the combination of PRT broadcast and SSP hill-placed. If the availability of SSP was limited, some farmers would use PRT alone. The demand for risk efficient alternatives could significantly increase if farmers could bear less than half the fertilizer costs at the current output price, although further research is required to say if a fertilizer subsidy could be justified on broader economic or social grounds.

Evaluation of economic returns of drip irrigation and local irrigation system: From June 2002 to May 2003, 827 drip irrigation systems were distributed and disseminated in Niger by ICRISA T and partners. Two types of systems were developed including the Thrifty system (TS) of 80 sq meters and a large commercial system (CS) of 500 sq meters. These systems were targeting two segments of the population based on gender. The small systems were targeted to women who are often excluded from the cash economy in rural and urban areas. The large systems were made to target vegetable producers some of which are located in peri-urban areas where the demand and income are relatively high. Development project partners found very appropriate to use these systems to address community deficiencies in basic nutrients and others used these as students – field- schools to teach students of biology and agronomic principles. These systems were distributed in the regions of Agadez, Tahoua, Zinder, Tillabery, Dosso (60 CS+173 TS) and the peri-urban Niamey (50 CS + 276 TS).

Since then, there was little monitoring and little was known on the level of uptake and use of these technologies. As a step towards a study on diffusion of drip irrigation systems in Niger, 2 zones were targeted: the peri-urban Niamey and the Dosso region where 130 CS and 363 TS were distributed. These areas differ significantly by the level of monitoring and evaluation. While in peri-urban Niamey, little monitoring and technical support was provided, in Dosso, these systems were largely supported by the Projet de Development Integree de la Region de Dosso and the "Ecole de Sante"'projects funded by the Luxemburg government.

In the region of Dosso, 47 systems were visited out of the 233 systems distributed. Overall, 44 systems i.e. (94%) were still functioning. In peri-urban Niamey, 97 systems were randomly visited out of the 326 systems disseminated. It was found that 56 systems (58%) were still functioning.

In order to assess the perception of users, the returns to using drip irrigation compared traditional practice as well the range of constraints facing users, a survey of 92 systems used by 68 producers was carried out in Dosso and Niamey. In addition, 21 producers using the traditional technology were surveyed.

In general, it was found that the economic returns to land for those using the drip irrigation systems was estimated to 526 FCFA/m2 against 336 FCFA/m^2 for those using the traditional practice. The returns to water, labor and fertilizers were perceived to be high by farmers. In general, to enhance uptake of the drip irrigation systems, (1) the diffusion points need to be well targeted, (2) people need to be well trained at fabricating water tanks that do not leak especially for small systems, (3) the technology has to be flexible to accommodate different types of crops, (4) the systems have to be larger because most vegetable growers own on average more than 80 sq meters , some of them who were given the small system did not find this useful, (5) access to cleaned water has to be improved, (6) the need for more demonstration. In effect, many farmers had the perception of low supply of water to plants and had to supply additional water with watering cans, (7) better use of the technology, only 2 have used the technology during 2 seasons during the year, (8) the need to link producers to better vegetable markets, more than 20% claimed to experience marketing problems and (9) the need to link farmers to credit markets as many farmers found the start-up capital very high.

In Dosso where NGOs have technically supported the systems, practically all systems are still operating. Around Niamey when no technical support and follow up was given about 60% are still operating. The diffusion of this technology is limited producers were because of limited monitoring and poor access to capital by producers. Policy and programs that will favor access to credit by producers is essential to enhance uptake of African market garden.

Uptake of Soil and Water Conservation Technologies in the Office de la Haute Valle du Niger (OHVN) in Mali (WCA)

Rationale: In many agricultural based developing countries, land degradation may occur at any time in any geographical region of the planet. It is limited neither by space and time nor by a particular natural circumstance. Among the various types of land degradation, soil erosion is the most important and an ominous threat to the food security and development prospects of many other developing countries. It induces on-site costs to individual farmers and off-site costs to society. Due to the presence of externalities arising from soil erosion, market prices do not reflect resource scarcity and individual farmers will have insufficient incentives to practice soil conserving agricultural practices. Accelerated soil erosion can be reduced by a combination of proper land management systems and appropriate soil and water conservation efforts. Incentives to promote soil and water conservation measures are, therefore, appropriate areas of intervention to mitigate the adverse effects of irrigation. Physical soil conservation structures technically have the potential to reduce soil loss by decreasing overland flow of water and to mitigate yield variability by reducing moisture stress on plant growth through retention of rainwater that would otherwise be lost to runoff.

Substantial progress has been made in the development and testing of potentially profitable technologies for improved soil and water management in West Africa. There is growing evidence that some of these technologies (e.g. rock lines, branch barriers, small dikes, vegetative bands, compost pits) are beginning to be widely adopted. However, the full extent of this adoption remains uncertain. There have been no systematic efforts to evaluate the degree or quality of adoption (i.e., correct use of techniques). Little is known about how many farmers are adopting these technologies, and there are no known attempts to record the extent of dis-adoption over time (e.g. when the special development project ends).

Past research has raised a range of hypotheses about the levels and determinants of the adoption of soil and water management technologies in West Africa. Questions have also been raised about whether this adoption is the result of incentives associated with specific types of development projects, the presence of cash crops, or some combination of the two. The purpose of study is to highlight socio-economic aspects of soil and water conservations (SWC) as it applies to subsistence farm households in the Office de la Haute Vallée du Niger (OHVN) in Mali.

Specific research questions addressed in this study are: What is the level of uptake of soil and water management (SWM) technologies? 2. What is known about the determinants of uptake and the relative importance of factors such as cash crops and technology promotion projects? 3. How do the levels of uptake vary by zone, household, and farm characteristics? Are some technologies more suited to wealthier farmers or to farmers with lower labor costs or to farmers with better access to product markets? 4. Are changes in household welfare, food security or total assets perceived by farmers? 5. Which drivers are most important for stimulating uptake?

Methodology: Following a participatory rural appraisal in 7 villages of the Office de la Haute Vallée du Niger (OHVN) involving about 100 farmers, a structured survey of households was conducted from 25 October 2002 to 15 November 2002. Twenty-six villages were selected purposely in the OHVN zone based on OHVN agents' perception of level of average uptake of soil and water management technologies in the village. Thus, 5 villages were assumed to have a high level of uptake, 6 villages with average level of uptake and 15 villages with low level of adoption of soil and water conservation methods.

In each village, an average of 20 households was randomly selected based on the census provided by the chief of village or constructed by the enumerator in the village. A total 531 rural households were selected and interviewed from October 25, 2003 to November 25, 2003. Households' decisions to use soil and water conservation methods are influenced by a number of factors. The effects of these factors are influenced by the nature of rural market imperfections. When market distortions occur, the subjective price of the good may fall within the price ban and make consumption and production decision non-separable. This implies that investments in soil and water conservation methods will compute with resources needed for current production or consumption decisions. To the extent that assets and factors differ across households market imperfections may also lead to differential investment in soil and water conservation technologies. Imperfections in credit/capital markets may also imply that households with higher savings or productive assets will be able to invest more in conservation methods. Overall, when market imperfections are important, the theory of investment behavior suggests inclusion of household characteristics and assets.

Results: Survey results showed that about 38% of surveyed farmers have adopted at least a soil and water management technology. Among these, stone bunds and stone lines were the most used representing about 11% and 22% of households respectively. In addition, more than 55% of households surveyed used inorganic fertilizers. Results from a Probit model showed that the decision to use stone bunds is explained by involvement in cotton production, access to product markets, credit, equipment and the perception of productivity gains. Governments and donors support policies should target poor households by enhancing access to credit and agricultural equipment that are necessary to enhance uptake of soil and water conservation technologies.

Production systems and Socio-Economic constraints in the Fakara (WCA)

Rationale: Frequent food deficits are still current in the Fakara region despite significant research efforts in the region. Farmers have developed economic strategies and social network that help them go through these difficult periods. Due to uncertainty (weather, prices) they have developed production system that allows them to minimize investment even though it compromises the level of production surplus.

The main objective of the study was to conduct an evaluation of farmers' strategies of agricultural production systems through understanding of farmers' behavior towards food deficiency in Sahel zone of West Africa. The study was then set to categorize Fakara households and draw implications for new technology development and dissemination in the region.

Methodology: The study was conducted in three villages of the Fakara region (Canton of Diantiandou). The villages chosen were Banizoumbou, Kodey and Tchigo Tagui. The three villages are quite the same in terms of agricultural production conditions. They were also already on-farm trial sites for the JIRCAS project. In each village, a sample of 30 farmers was drawn from a list of key informant used by the project. Thus a total of 90 households were interviewed using a set of questionnaires.

Based on the data collected households are classified in three categories. The primary classification criterion is household assets. The study used the reported type of livestock possession to categorize the household into no livestock category, those with small ruminants only and those with large ruminants (cattle). It should be noted that households with cattle often also have small ruminants. Large livestock owners are expected to be the wealthiest of all, with the small ruminant only group following and the poorest will the group with no livestock at all. This categorization is important and follows farmers' classification of wealthy people. In fact in the local language for the region, there is a word used for wealth and livestock are the same time.

Results: Manure is quite widely used by these farmers and its use depends on resources of the household. While 85% of the livestock group members use manure, the percent users is as high as 98% of the large ruminant group members. Inorganic fertilizer use is quite different for the three groups. While only 25% of no livestock group has reported buying inorganic fertilizer, up to 50% of the other two groups have purchased some. However, average quantity purchased is only 36 kg per household for the large ruminant group, 24 kg for the small ruminant group and only 7 kg per household for the no livestock group. Given that inorganic fertilizer is the most expensive purchased agricultural input in the region, its quantity used can be a good proxy for amounts farmers are investing and/or are willing to invest in agriculture.

The first group (no livestock) is expected to be the one most concerned with food shortages. All household resources are primarily geared toward making sure enough food is available for the year. This group would be most likely to have few adopters of agricultural innovations. The behavior is justified by lack of all resources to devote to agricultural innovations. For this group extra labor will most likely serve as laborer in other farmers' fields and capital is almost not available to them.

The second group is composed of households with only small ruminants in their herds. For this group agriculture will be the most important activity and their often looking for options to improve their production. They are not food constrained as the first group. Farmers in this category are expected to be able to invest additional labor and/or small amount of capital into agricultural innovations. Adoption rate of new technology in this group is expected to be high especially for labor intensive ones and those requiring limited cash investment.

The third group is that of the wealthiest farmers with animal herds composed of small ruminants but also cattle. Farmers in this third group are often very influent in the village. Even though they have crop production activities, it is not necessarily their most important one. They are often looking for opportunities to invest in lucrative activities. They will adopt agricultural innovations if profitability of such investment can be demonstrated to them.

Technology development for this region should take into account the fact that households are different in their investment and risk handling capabilities. Technologies that require cash investments will have a smaller number of potential adopters unless strategies are devised to increase liquidity and risk handling capacity for those farmers. Labor intensive ones can also run into availability constraints because poor households are often too busy making sure that enough food is made available immediately that they do not devote enough time to their crops. Very poor farmers (most often without any assets) have limited investment risk bearing capacity and are more unlikely to invest in technologies requiring cash investments.

<u>Priority 5B: Making international and domestic markets work for the poor</u>

<u>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</u>

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

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 Targets 2006 : Profitable marketing channels and outlets for dryland grain legumes and tradable coarse grains in domestic and international markets identified
: Strategies that enhance farmer access and utilization of productive inputs and linked services that enhance competitiveness developed

1C.1. Policy brief on re-energizing agriculture through diversification using the example of SAT India

<u>**Diversification of agriculture towards high value crops: role of urbanization and infrastructure (Asia)**</u>

<u>Objectives:</u> 1. Document current trends in agricultural diversification towards HVCs
2. Identify major factors driving or impeding diversification

The study hypothesizes that demand for HVCs is driving their production while lack of adequate infrastructure and market support impedes their supply

Results: In India, demand for high-value food commodities (HVCs) such as fruit, vegetables, milk, meat, fish and eggs are fast increasing as compared to food grains. This is an opportunity as well a challenge for millions of smallholder farmers who are over 81% of total farm population in India. High-value agriculture has a comparative advantage over staples in production and labor use, and thus is reckoned as an important strategy for income augmentation and employment generation. Besides, integration of global markets is creating export opportunities for HVCs in developing countries.

Urbanization is a key determinant of demand for HVCs because of higher per capita income, change in tastes and preferences and greater participation of women in labor markets. About 28% of India's population lives in urban areas and by 2020, the urban population is expected to be 35% of the total population.

In general, incidence of high-value agriculture is more in districts close to urban demand centers. The share of HVCs in total value of agricultural production declines as one moves away from the major urban districts, except fruit, which appear to be more prominent in near-urban districts. This is because fruit are grown in their niche production regions due to agro-climatic factors besides being close to demand centers. The magnitude of high-value agriculture in near-urban districts is variable and could be explained by the existence or lack of transportation connectivity. The near-urban districts identified in this study were grouped into three categories based on the number of national highways passing through them, i.e., no highway, one highway, and 2 or more highways. It is found that 25 near-urban districts are not connected with any highway, 45 with one highway and 21 with 2 or more highways (Table 2). Interestingly incidence of high-value agriculture is more in the near-urban districts connected with one or more highways (37%) compared to districts with no highways (28%).

Rainfed areas, lagging far behind from the irrigated areas, are emerging important domains for HVCs to augment employment and income. Promoting rainfed areas through appropriate infrastructure development for agricultural diversification would have far reaching implications on the developmental and poverty alleviation programs. However, infrastructure required for high value agriculture is different from that of staples and non-food commodities. Being perishable, HVCs require refrigerated transport, cold storage and immediate processing. Considerable public / private investment is required to facilitate such investment and will have to be matched with the demand drivers and also supply side factors.

Options to mitigate market risks and reduce transaction costs include establishment of special markets for high value commodities in rural areas and linking farmers to industry / retail chains etc through institutions such as producers associations, cooperatives and contract farming. The modification of the existing Agricultural Produce Marketing Act, 1966, by the government of India is a step in the right direction.

1C.2. Synthesis report on strategic assessments of commercialization of market opportunities for SAT crops

Report on Domestic, regional and international groundnut market prospects in (WCA)

This report reviews the domestic, regional and international market prospects for groundnut in WCA. In West Africa, though all the countries that produce groundnut are prone to Aflatoxin contamination, Africa in general, is considered particularly problematic by international buyers because the production chain in each country (with the exception of South Africa) is fragmented, production systems have been insufficient to address the problem, Aflatoxin monitoring by crop is virtually nonexistent, and pre-shipment inspection services are perceived to be lacking in reliability.

Unfortunately, international trade in groundnut is based on confidence and reliability in terms of supply as well as product quality. The current EU regulations on Aflatoxin have certainly contributed to an increasingly conservative tendency among European buyers, who are unlikely to take any unnecessary risks with West African based products.

To re-enter the world groundnut market (and particularly the European market, which offers perhaps the greatest potential), export prices would have to compete favourably with Chinese groundnut, which is abundant, cheap, and enjoys a favourable reputation in terms of reliable supply and reliable quality. As recent prices for Chinese groundnut are of the order of \$650 per MT – the same price as production of a ton of edible groundnut under irrigation in Senegal, the current and foreseeable margins of return are not in any case favourable to the re-entry of West African exports on to the world market.

Yet, although the trade linkages are not as established (or as cheap) as those between West Africa and Europe, the South African market does represent a significant opportunity for West African producers. Due to a poor harvest in 2003, South Africa has been importing groundnut from Southern Africa and even Argentina at premium prices – over $700 per MT (unsorted and CIF) in Malawi. There may be scope for entry into the South African market once the Aflatoxin issue has been addressed by improved management and monitoring of product quality at the crop level.

The primary conclusion of this study is that there is a need for West Africa to improve the production chain of the groundnut sector with initial emphasis on production to satisfy national, sub-regional and even regional demand.

1C.3. Seed supply systems in WCA: Lessons learned for R4D published

<u>Groundnut seed systems in West Africa: current practices, constraints and opportunities (WCA)</u>

During the last 30 years, donors and governments have invested more than US$ 125 million in variety development, seed production and distribution projects in Mali, Niger, Nigeria and Senegal. More than 39 groundnut varieties were developed, adapted, introduced and released. However, the returns to these investments are low due to limited uptake of newly bred modern varieties. This is explained by limited access to seed of new varieties, limited supply of breeder seed, uncertain demand, missing or poorly functional national variety release committee, lack of integration between input and product markets, and lack of enabling policies and institutional environments. There are opportunities to exploit regional seed trade, enhancing the utilization of the large seed infrastructure, improving the interface between the public and local village seed systems and establishing sustainable community based seed systems.

The major constraints limiting the performance of groundnut seed systems include:
Limited access to seed of newly bred varieties; Limited supply of breeder / foundation / certified and commercial seed of varieties preferred by farmers or required by the markets; production subsidies and inefficiency; thin and uncertain demand; missing or non-functional national variety release committees are missing, or meet irregularly; weak integration between seed and product markets and Lack of enabling policy and institutional environments.

These factors have largely contributed to the under-development of the seed industry. However, there are opportunities around which sustainable seed supply systems could be developed. These include potential for regional seed trade, availability of seed infrastructure within countries, a large number of farmers already trained at seed production techniques through various rural development projects, NGOs or research institutions and large oil processing companies. These opportunities include the potential to exploit the regional market, the existing large seed infrastructure, fostering interface between the public, private and community-based systems, and overall the development of sustainable community based seed systems.

1C.4. Study on institutional arrangements for collective marketing in groundnut and pigeon pea in Malawi completed by 2006.

<u>Linking smallholder pigeonpea and groundnut farmers to product markets in Malawi (ESA)</u>

A draft monograph on "Livelihoods and market linkages: Social capital in linking smallholder pigeonpea and groundnut farmers to product markets in Malawi" is under revision for publication. The study assessed institutional and social factors that condition smallholder collective marketing. The study investigated why some smallholder groundnut and pigeon pea marketing clubs performed better than others. Three specific objectives were pursued: (i) To identify constraints to and opportunities for groundnut and pigeonpea production and marketing; (ii) To investigate why some marketing clubs succeeded while others did not; and (iii) to draw lessons that inform research and development policy.

Results showed that the marketing strategies for both grain legumes bore some similarities and differences. Whereas groundnut marketing was more organized and in terms of marketing clubs and an assured market through NASFAM, pigeon pea marketing was dependant on a multiplicity of actors (vendors, middlemen, buying and processing companies) in the market chain and greatly influenced by local processing companies.

Collaborating Institutions and Scientists:
NASFAM : Field extension officers
ICRISAT : J Alumira

1C.5. Markets and Commercialization of Legumes (ESA)

After a critical reflection from the experiences of the Sorghum and Millet Improvement Project (SMIP) and review of the legume sub-sector studies in the region, it was decided in late 2003 to develop a regional program on commercialization with interest to explore opportunities for improving market access for tradables (mainly focusing on legumes) considered to have better domestic, regional and international market opportunities. Grain legumes and oil crops are important food and cash crops for smallholder farmers because of their adaptation to marginal biophysical conditions and are grown by resource poor farmers without requiring substantial external inputs. Grain legumes, particularly chickpea and pigeonpea are widely adapted to diverse agro-ecologies of the region and are together grown in about 1 million ha. Groundnut is an important legume and oil crop that is grown in about 3.7 million ha in the region. Groundnut is a major source of cash for smallholders and is adapted to areas of low and unreliable rainfall.

Improving the value chains for these legumes would help poor farmers overcome severe nutritional deficiencies that result from diets lacking in protein and oil. They are especially beneficial for growing children who suffer from widespread malnutrition and cannot consume huge quantities of starchy staples. Higher cash incomes and better nutrition can reduce household vulnerabilities to climatic shocks (e.g. drought) and diseases (e.g. HIV/AIDS and malaria). Apart from direct cash income benefits, diversification into grain legumes also provides environmental sustainability benefits through fixing atmospheric nitrogen that will benefit other crops (sorghum, maize, finger millet) in the system. The crop byproducts also serve as feed and fodder for livestock and allow smallholders diversify livelihoods through crop-livestock integration. Owing to their deep root systems, pigeonpea and chickpeas draw water from subterranean levels, allowing farmers to secure a harvest when most other crops fail.

The initial assessments seemed to show that overall the dryland legumes together offer a good opportunity for farmers and agribusinesses in semi-arid areas to benefit from markets for increasing their cash incomes and diversifying their livelihoods. Given these opportunities, the research on legumes commercialization aimed to assess the real potentials and constrains that these crops offer in the context of liberalized markets and the strategies for improving market access and competitiveness of smallholder producers in domestic and international markets.

Objective: Assess the structure and performance of the markets for dryland legumes and identify the major constraints and opportunities for improving market access and competitiveness in domestic and international markets

Methodology: Commodity sub-sector studies that involved farm level technology adoption and marketed surplus studies, market and value chain analyses and pilots to test alternative institutional arrangements for linking farmers to markets

Main findings & policy implications: The results from these studies have shown that the marketing channels for legumes are characterized by long and complex marketing chains and high transaction costs which considerably lower the farmers' share of the final consumer price. The marketed volumes remain small and highly variable depending on weather conditions, but in some areas up to 70% of the produce is marketed. For pigeonpea, the domestic market demand remains limited, but exports to India represent a significant market outlet for pigeonpea, making ESA the second largest exporting block for pigeonpea in the world. Export competitiveness to the Indian market is largely limited by pigeonpea exports from Myanmar and other competing substitutes (yellow pea imported from Canada and France). The technology adoption studies verified that competitiveness can be enhanced through adoption of improved high-yielding, disease resistant (Fusarium wilt), and consumer-preferred varieties (e.g. large seeds with cream color widely adopted in Babati district and eastern Kenya). For chickpeas and groundnuts, the domestic markets are more developed and export opportunities more diversified (including the Middle East, south Asia, Europe and the USA). In the international markets, there is stiff competition for exports from several major producing countries and major players in export markets. The value of exports is significantly higher for Kabuli types and prices are closely correlated with the grain size. Since the cost of production and agro-climatic requirements are similar between the Desi and the newly developed Kabuli types adapted to tropical conditions, there is a higher incentive for farmers to switch to growing Kabuli types.

With increased availability of profitable and pest and disease resistant Kabuli types, this trend is now already apparent in all the major growing countries (e.g. Ethiopia and Tanzania).

For groundnuts, there are growing domestic and regional markets but export opportunities are limited by food safety and quality concerns associated with aflatoxin contamination (a carcinogenic substance caused by the fungus, *Aspergillus flavus*). This has promoted new research efforts to reduce aflatoxin contamination and establishment of low-cost testing, traceability and certification systems. This has allowed Malawi to re-enter the export market for groundnuts after many years of non-competitiveness in these markets. The studies have also identified the different quality requirements for groundnuts used in the growing confectionary industry and edible groundnuts and for oil extraction. The availability of cheaper substitutes (soya and palm oils) has also contributed to declining demand for groundnut oils.

Overall the market assessments have shown that improving competitiveness requires access to high quality seeds of market preferred varieties and other production inputs that increase yields, save on resource costs and improve product quality to meet the increasingly stringent and dynamic market requirements (especially for export markets). Facilitating the development and adoption of good agricultural practices, quality control and grading systems is an important factor in enhancing competitiveness. Along with the need to expand the volume of trade, competitiveness requires cutting production and marketing costs and enhancing the reliability of supply.

On market access for smallholder farmers, the studies have shown that marketing channels in many rural areas are characterized by long and complex marketing chains and high transaction costs which considerably lower the farmers' share of the consumer price. In Eastern Kenya, about 45% of the grain sold and 36% of the transactions are undertaken at the farm-gate. About 90% of the grain sold by farmers is transacted at the farm-gate or adjacent village markets. The study also shows that rural wholesalers and brokers jointly control over 80% of the grain sold by farmers. About 75% of the grain was sold immediately after harvest when local supply is high and prices are low. Asymmetric information is pervasive in grain pricing and most rural traders do not pay a premium for better grain quality.

A pilot study on the potential of producer marketing groups to increase market participation and competitiveness showed that indeed such groups can play a significant role in facilitating vertical and horizontal coordination in input and output marketing for small producers. The prices paid to farmers by the groups after covering marketing costs were about 20-25% higher than prices paid by brokers and middlemen in rural villages. This was possible through quality control, bulking, temporal arbitrage and direct access to buyers at the upper end of the value chain (urban wholesalers and processors).

The policy challenge is to facilitate the emergence of efficient and effective farmer organizations that accelerate the uptake of improved technologies and open market opportunities for small producers often trading in small volumes in areas with limited market access. Such groups and rural institutions are however unlikely to emerge and attain economic viability on their own without the support of governments and other external agents. Market orientation, competitiveness and business motives should be the guiding principles for such groups. Mechanisms that facilitate the transition of such groups into effective business cooperatives are highly needed in many countries in the region.

1C.6. Value chain analysis completed for groundnut and pigeonpea in Malawi and Mozambique by 2006

Linking Farmers to Markets: Diagnosis of Constraints and Opportunities for Expanding Groundnut Marketing in Malawi

While farmers in southern Africa have been relatively responsive in adopting new and early maturing varieties, firm linkage to markets have been weak. This has tended to compromise the rates of continuous adoption of several technologies and in some cases even leading to some dis-adoption.

The history of agricultural technology development and transfer in Africa depicts a map of heavy concentration on facilitating farmers to adopt technologies but with almost no business in enabling such farmers to link to markets so that the vent for surplus can be realized. It has been assumed that the invisible hand would take its course but apparently the market imperfections are too huge to be assumed away. At best socio-economic researchers would come in and conduct some agricultural marketing studies for those targeted commodities but those have largely remained academic because of the failure to adopt a participatory private sector approach. Practical solutions to address the missing link between farmers and product markets are therefore a significant objective of this study.

Objectives: Identify production and marketing constraints of groundnut farmers along the lakeshore of Malawi Explore options for linking groundnut farmers to product markets for more sustained adoption and improved incomes.

Methodology: Ninety smallholder groundnut farmers were interviewed along the lakeshore in Malawi with a view to understand the production constraints and how these are linked to marketing. Marketing challenges facing groundnut farmers were also investigated. This was followed immediately with a traders' survey. About 30 traders of different commodities were tracked for about one month in the peak of groundnut marketing season. It was necessary to deal with traders of all types of commodities –and not only for groundnuts because the latter hardly exist. The interest was to assess the different marketing functions from the farm gate to the trader to the processor or exporter and evaluate the pricing and quality control dynamics including price determination at different levels. An investigation of the policies, rules and regulations affecting the groundnut trade was also carried out to determine the extent to which they are facilitating or constraining the viability of the groundnut sub-sector.

The role of the private sector—wholesale buyers, processors and exporters was also investigated by visiting and discussing with prominent firms in Lilongwe to establish their role in the marketing chains and to determine areas and ways in which the two could be more amicably linked.

Preliminary Findings: Most of farmers maintained less than one hectare of groundnuts raised from improved seed provided by ICRISAT. Yields are low averaging about 400kg of shelled groundnuts. There are generally very poor marketing arrangements. Contract farming is unheard of in groundnuts although cotton contract farmers can be found in the same groundnut growing communities. In fact if contracting for groundnuts is to be initiated, there are lessons to obtain from cotton. Price formation is poor and farmers seem to be facing a big price risk at marketing time. In the first place, a significant amount of groundnuts is sold on the farm before harvest, mainly because of hunger. Farmers need money to buy food and other essential commodities before the groundnuts mature. Obviously, given the circumstances, they would be willing to go for any price the buyer declares because they are desperate at that time.

At normal harvesting time, farmers are invaded with a swarm of "buyers" or practically assemblers who have been sent with cash from big traders and transporters or processors from the cities of Lilongwe and Blantyre as well as from the border posts. Price negotiation is through the head men but the ceiling is already set by the traders. It is envisaged that these prices are normally lower than what they could be under normal competitive conditions. As a result the margins are likely to be quite big between farm gate and export prices even after taking into account transport and transportation costs.

In effect, there is a wide gap between actual and potential conditions in the marketing conditions of groundnuts and especially in price formation. The first steps are to facilitate, train and empower farmer groups at the village level to enable them, in the first place to have the basis to negotiate for better prices as well as training them to recognize that better quality groundnuts can also have a premium price from the processors.

A great potential exists to improve farmers' incomes and food security from groundnuts in Malawi and there is need to continue with this work in the future.

1C.7. Value chain analysis completed for pigeonpea and chickpea in Kenya and Tanzania

Pigeonpea sub-sector study in Kenya

This study was summarized and synthesizes several fragmented studies on pigeonpea in Kenya. It targeted to identified the constraints that limit full exploitation of the potential of pigeon peas for dryland agriculture. The methodology adopted was that of a sub-sector approach to examine several actors from the pre-production to the marketing and utilization chain. The result is expected to be the source book for the pigeon pea sub-sector in Kenya and facilitate similar synthesis of the legumes sub-sectors at the regional level. Development partners like TechnoServe and Catholic Relief Services have already started using these findings for as part of their ongoing efforts for improving legume productivity and market access in semi-arid regions.

This study has informed policy decisions on strategies for enhancing competitiveness of pigeon pea production in East Africa in general and in Kenya in particular. It has identified strategies, constraints and opportunities for for promoting high value pigeonpea varieties in Kenya and in the region. The findings of this study have contributed to enhanced communication and partnerships with the private sector in Kenya for the development of the legumes sub-sector.

Similar to the chickpea study in Ethiopia, this study involved extensive consultations and interactions with a range of stakeholders including farmers, farmer organizations, private sector, extension departments, NGOs, researchers and government officials. The study used a sub-sector approach to identify constraints and opportunities at different points in the pigeonpea production, processing, marketing and consumption chain. It reviewed the existing literature and brought together a set of recommendations for harnessing the opportunities that lie in the pigeonpea sub-sector. A value chain analyses approach was used to assess the structure and functioning of pigeonpea markets. Availability of such information has facilitated the interactions with the private sector and is becoming useful in linking smallholder producers with wholesalers, processors and exporters. Development partners (e.g. TechnoServe and Catholic Relief Services and donors (e.g. USAID and IFAD) have also benefiting from the findings.

Chickpea sub-sector study for Ethiopia

This study is expected to lay the foundation for better understanding of the constraints and opportunities facing the chickpea sub-sector in ESA region. It was undertaken based on the request of the Ethiopian Farmers Project (IPMS) jointly undertaken by the Ministry of Agriculture, Ethiopian Institute of Agricultural Research and ILRI. The study is expected to influence future priorities and strategies of Farmer Organizations and pulse traders, processors and exporters in Ethiopia. The methodology and the approach used are very useful to researchers and policy analysts.

This study has informed policy decisions on strategies for enhancing competitiveness of chickpea production in Ethiopia and helped the IPMS project and the Ministry of Agriculture define new approaches for promoting high value chickpea varieties. It has also informed the Farmers' Union on how best to organize its chickpea production and marketing options and highlighted the challenges faced by Ethiopian pulse exporters.

The study involved extensive consultations and interactions with a range of stakeholders including farmers, farmer organizations, private sector, extension departments, NGOs, researchers and government officials. The methods involved literature reviews and data collection using formal and informal approaches. A value chain analyses approach was used to assess the structure and functioning of chickpea markets. Some of the results have already been presented at the IPMS workshop on agri-business development and contributed to the inclusion of chickpeas by the Ministry of Agriculture and EIAR under the priority commodities identified for technology scaling up in the country. Availability information has also started to attract funding and other partners (e.g. Catholic Relief Services and the Ethiopian Seed Enterprise) to improve productivity and market access for chickpeas.

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 by 2009 and new knowledge shared annually with partners

MTP Output Target 2006: Appropriate innovative integration/market linkage models identified in at least two SAT countries

1D.1. Market linkage studies and capacity building measures for institutional innovation and strengthening of public-private sector linkages undertaken.

Institutional innovation and strengthening of public-private sector linkages: Coalition approach for effective market linkages (Linked with GT-CI)

The objectives of this study are a) to conduct an evaluation of the emerging patterns of institutional partnerships for effective market linkages and b) to provide policy and programme guidance on the optimal arrangements involving public and private partnerships. A unique feature of this study is the coalition approach, i.e., the process in which distinct or independent entities/institutions work together as a single unit while keeping their identity, for the common goal with synergistic effect. The coalition approach helped to present the right kind of incentives to benefit the poor sorghum farmers, feed manufacturers, poultry producers, and the scientists. The following are the key issues based on the study

Research, practice and coalition building: The small-scale poor sorghum producers with less than 1 ha of land are faced with inherent weak social capital and poor access to markets, which restricts their ability to influence market demand. Besides improved sorghum technology for higher yields and returns the study explored institutional arrangements to establish an organic linkage between research, producers and end users (industrial users of sorghum) that will lead to the overall welfare of producers and end users. Various 'policy networks' have been identified in research on knowledge utilization and policy-making ranging from 'policy communities', with access to privileged information and decision-making, to 'advocacy coalitions' that share beliefs and aim to change policy. The sorghum 'coalition' is a 'network' in the sense that the participants have voluntarily entered into the collective, they also remain part of autonomous organizations, and they come together for mutual or joint activities. As a group of organizations with different values and interests, the Sorghum Poultry coalition could also be labeled as an 'issue network'. Alternatively, as distinct but related organizations, including private companies, who have come together to improve their performance or position, it might be categorized as a 'strategic alliance'. Although such labels are only of limited use, they can be helpful in exploring how different types of networks or coalitions will require different strategies for successful innovation, learning and communication to ensure impact on poverty reduction.

Shared and complementary interests: The sorghum coalition's shared interest at the level of overall goal, and complementary interests expressed through outputs at the lower level, allowed it to work as a team. The decision-making is based on consensus building rather than advocacy or campaigning. This entailed the creation of incentives that drew each member into the coalition but also kept them investing in it. These incentives were primarily economic but not entirely.

Management and learning: Another aspect of planning that the coalition rightly took extremely seriously was selection of partners. It has been pointed out that it is better to have a small number of dedicated organizations in a network than dozens of marginally committed ones (Creech and Willard 2001). The coalition followed this model as well as monitoring a complete membership involved from start.

Communication and trust: It is in the area of communication that the biggest differences between networks can be found. The sorghum coalition members respect and trust each other, not necessarily in all senses and circumstances, but in ways that their enterprise requires. Newell and Swan (as quoted by Church et.al 2002) have distinguished between three types of trust:
Companion trust: that exists in the context of goodwill and friendship
Competence trust: trust in others' competence to carry out the task agreed
Commitment trust: made fast by contractual or inter-institutional agreements, that can be enforced.
In this case, the sorghum coalition achieved all three, but most particularly competence trust. Regular dialogue was critical, and nurturing relationships with courtesy was a feature, but equally important was the emphasis on results.

Scaling up: Private sector participation ensures the role of private seed industry in enhancing the technology access to poor sorghum growers. Poultry producers showing interest in partnering with the farmers by way of supplying poultry manure and purchasing the surplus sorghum grain making linkage more stronger.

Increased income for the sorghum growers: The sample farmers realized three to four fold increase in yields by adopting improved technology (improved cultivars and practices) with proportionate increase in net farm income (Parthasarathy Rao et.al. 2004).

Empowered local farmers associations: Village level farmers associations experienced new strengths in bargaining with industry. The practice of grading and bulking has the potential of opening new opportunities in other alternative uses.

Time lag in technology transfer is minimized because, at every stage stakeholder workshops were organized to disseminate and receive feedback. Sorghum crop scientists got feedback on farmers preferences in improved varieties and poultry scientists expanded their knowledge in matching their research with end user (feed manufacturers) requirements. In a nutshell, the sorghum poultry coalition, Andhra Pradesh, India was successful because the partners have had
common goal and clearly defined roles and responsibilities
ability to articulate problems and prospects
empathetic ability to fit themselves in broader objective
enthusiasm to work in groups and sharing the synergies

Clearly it will take some more seasons to judge the strength of the research-farmer-industry coalition. But if that proves sustainable, being generic in nature this 'coalition approach' can suitably be adapted to other crops and in other places, where market linkage is constraining crop production.

Collaborating Institutions and Scientists:

ILRI	: Michael Blummel
ANGRAU	: A Rajasekher Reddy
ICRISAT	: P Parthasarathy Rao, BVS Reddy, CLL Gowda, K Gurava Reddy
Feed Industry	: CLN Rao
Farmers Federation	: P Chengal Reddy
Poultry Federation	: Ch. Janardhana Rao

Linking small scale sorghum and pearl millet producers to processors through innovative market linkage models (Asia)

Purpose: The CFC project titled "Enhanced utilization of sorghum and pearl millet grains in the poultry feed industry to improve livelihoods of small-scale farmers in Asia" aims at improving the livelihood of farmers of coarse cereals in designated clusters of villages in Maharasthra and Andhra Pradesh states of India besides having its operations in China and Thailand by increasing their farm income by 15% in three years. The role of savings in marketing costs and increase in farm incomes has been considered to be important besides increasing productivity for enhanced income of farmers.

Background: Presently the farmers in the project area are following the traditional supply chain for sale of sorghum and pearl millet where the produce moves through a series of intermediaries who add cost at each successive step in the chain. The chain has incorporated many deficiencies and has become inefficient in course of time. Several innovations in supply chain of industrial products such as maize, cotton and barley are the result of either farmers uniting themselves as co-operative unions to empower themselves or corporate intervention for procuring their raw materials. There are many benefits for farmers as well as corporate sector in supply chain innovations. The farmer gets assured price, technical guidance and improved access to inputs and credit while the corporate sector gets assured supply of superior quality raw material.

Results: Drawing insights from various supply chain innovations and the features associated with marketing of sorghum and pearl millet for poultry feed, "bulk marketing" has been suggested as the best supply chain modification to be implemented in project areas for promoting sorghum and pearl millet for poultry feed. Besides increasing the bargaining capacity of farmers the advantages of bulk storage and marketing arise from seasonal increase in prices of coarse cereals as well as ability to cater to other industrial sectors (alcohol, breweries, starch etc.) now dominated by alternative cereals. Hence effective storage management along with market intelligence to make sales decisions will be an important component of bulk marketing.

Bulk marketing refers to the process of selling bulked produce directly to the bulk buyer (processor) in order to minimize transaction cost and realize mutually beneficial price (for both the buyer and the seller). Under the conventional agricultural supply chain farmers sell their produce in the markets through commission agents. Product gets exchanged between many hands before reaching the final consumer.

The modified supply chain generated from the bulk marketing eliminates the drawbacks of the conventional supply chain and makes the market perfect for both the farmers and the buyer. The supply chain generated out of bulk marketing eliminates many conventional middlemen by directly linking the farmers with the processors or the bulk buyers. Since the farmers get united, their requirement of inputs is also in bulk and they get linked with the input dealer. This ensures supply of quality inputs at reasonable prices. The input dealers also save the money spent on distribution and publicity. This benefit of reduced costs is passed on to the farmers. Bulking of produce creates collateral security for the farmers' produce against which the banks can extend loans. This prevents exploitation of the moneylenders. The source of information also gets enhanced, as the farmers are able to get the first hand information on market prices and quality of produce from the ultimate buyers.

This enhanced supply chain provides tremendous scope for linking the buyers with the farmers. As bulk marketing ensures assured supply of quality produce at reasonable rates, buyers come in direct contact with the farmers and give their quality requirements for the produce which the farmers tries to maintain. As the involvement of middlemen is eliminated the transaction costs are cut down paving way for better profits to the buyers. The benefits of bulk marketing would directly come to farmers and result in enhancing their income, thereby fulfilling the goal of increasing income of small-scale sorghum and pearl millet farmers. It is suggested that the local *arhatiyas* (commission agents) and the brokers should be made a part of the modified chain in the initial 2-3 years for smooth transition. The presence of three critical inputs has been advocated for successful implementation of bulk marketing during the project implementation period:

Constant knowledge support and guidance by ICRISAT and project partners
Strong and sustained association among farmers
Exploitation and utilization of value proposition of coarse cereals.

1D.2. Price trends and competitiveness of mandate crops (Preliminary work completed)

Prices of agricultural products are inherently volatile because of they are susceptible to both supply and demand shocks in the world agri-food market. On the demand side, the price of an agricultural product is influenced by a number of factors. These include incomes, urbanization, health issues, people's tastes and preferences and values, and relative prices of substitutes or complements. On the supply side, production costs and improved technology, weather and disease related shortcoming, or conversely, the production of bumper crops work together to determine agricultural product prices. When the cost of production rises they are passed on in the form of higher prices for agricultural products. There are also other variables that impact on agricultural product prices. These include exchange rate changes and government macroeconomic and trade policies. The rising incomes, falling transportation costs, improved technology, and evolving international agreements have led to substantial growth in the volume of trade in agricultural products, thus causing fluctuations in world agricultural product prices.

According to FAO 2004, in spite of recent strengthening of agricultural commodity prices after a prolonged decline since the mid 1980s, continue to be at historically low levels and their long term decline relative to manufactured goods continues. Real prices have also fluctuated considerably along the long term declining trend. The ICRISAT mandate crops are no exception to this with real prices of all mandate crops declining. The real prices of sorghum, chickpea, pigeonpea and groundnut (measured as unit value of exports) has declined by 2-3 % between 1970 and 2004. Only between 2000-2004 there has been a reversal in the trend particularly for sorghum and groundnut. Several factors contribute to the decline as also the year to year fluctuations.

1D.3. Commodity situation and outlook reports developed for the vision and research agenda for sorghum, pearl millet, chickpea, pigeonpea and groundnut (Global)

The vision and strategy for ICRISAT cereals, pulses and oilseed was redrafted to reflect the changing scenario for these crops both on the demand and supply side that would enable identification of potential areas of focus research up to 2015. The socioeconomics team enabled the Crop Improvement (CI) scientists to update the trends in area, production, productivity, utilization and trade of mandate crops. Using these trends as a basis, future areas of thrust and research were developed for each crop. These were subsequently reflected in the overall strategy of the Crop Improvement Theme. For example, socio-economists highlighted the changing consumption patterns of crops like sorghum and pearl millet from food use to other uses at the same time highlighting niche areas where food use will continue to be important. The faster growth in edible groundnut use compared to groundnuts for oil was notable as well.

Collaborating Institutions and Scientists:

ICRISAT	:	P Parthasarathy Rao, MCS Bantilan, J Ndjeunga, CLL Gowda, D Hoisington, BVS Reddy, SN Nigam, PM Gaur, KB Saxena

1D.4. *Mixed crop-livestock systems in South Asia: enhancing livestock productivity to benefit the poor (Asia)*

Objectives:
To synthesize the results and key findings from the ICRISAT – ICAR collaborative project on increasing livestock productivity in mixed crop –livestock systems in South Asia
Update data in tables and graphs and data analysis from earlier reports as appropriate
Rewrite sections from earlier reports as appropriate

Background: From the perspective of poverty reduction it is important to identify agricultural activities that are accessible by the poor, are labour intensive, generate sufficient income, and have enough potential for growth. Livestock fit well in this scheme of poverty reduction. They play a multiple role in enhancing the livelihood of the poor and enabling them to climb up the ladder of poverty reduction. About 70 percent of the rural poor in the developing world are associated with livestock production and they receive a higher share of their income from livestock than do the rich (Delgado et al 1999). As a source of food, they contribute towards reducing the problem of malnutrition particularly among the children and lactating mothers. Delgado et al (1999) found a negative relationship between per capita animal protein intake and incidence of undernourishment in developing countries.

Most developing countries experienced rapid increases in per capita income and urban population during this period, which eventually translated into disproportionate increase in demand for animal food products. These trends are likely to continue on account of three main factors. First, the current per capita consumption of animal food products is much less in developing world than in developed world. Second, the factors underlying demand growth in the recent past have been quite robust, and are unlikely to diminish in the near future. Third, the spreading of supermarkets provides an easier access to ready-to-eat convenience animal based foods. The projections indicate a substantial increase in demand for livestock food products by 2020 (Delgado et al). Besides, increasing integration of global markets is also opening up new opportunities for exports of animal food products. With unfolding of the process of globalization the volume of world trade in livestock products has been increasing. Evidence indicates that many developing countries are competitive in production of livestock products, but they lose in the international markets because of heavy protection to livestock production in major exporting countries such as EU and the US, lack of compliance of sanitary and phyto-sanitary standards and inefficiency in processing.

Livestock in most developing countries are raised as a part of mixed farming systems wherein there is considerable synergy among the system components. This leads to a more efficient use of farm resources. What is needed is a coherent picture of the characteristics of crop and animal production within mixed farming systems, and the way these systems are changing in different regions. There is a paucity of information on farming systems research that incorporates animals interactively with cropping systems. Research, policies and institutional interventions will be more effective in promoting agricultural growth and rural development if these:
• Recognize strong nexus between crop and animal production.
• Appreciate the complexities of mixed systems and the need for differential interventions in different systems.
• Have a better understanding of the prevailing patterns of animal ownership and management.

The study will be published as a book which will provide an analytical description of the prevalent mixed farming systems in South Asia and follows a systems approach that incorporates crop and livestock production together with agro-ecological conditions, risks and returns from different farm activities, soil management and socioeconomic conditions that influence farmers' choice of enterprises. Specifically, it provides:

A comprehensive and integrated view of the structure and dynamics of livestock sector in South Asia and its role in poverty reduction.
A Typology of mixed crop-livestock farming systems for South Asian countries.
A agro-ecological and socioeconomic characterization of each of the systems identified in the typology.
An understanding of the relative importance of agro-ecological, technological and socio-economic factors in influencing the type and density of species, adoption of livestock technologies, and productivity of the system.

1D.5. Future outlook for dryland crops using the IMPACT-WATER model

In response to socioeconomic and biophysical changes over time, SAT agriculture has undergone significant changes - the share of dryland cereals in the total cultivated area has declined globally and especially in Asia. Investment in irrigation and changing consumption patterns induced by income growth and urbanization have prompted farmers to diversify production into other crops like maize, oilseeds, soybean, cotton and rice, thereby lowering the relative importance of dryland crops. To the extent that the share of these crops in consumption, production and marketed surplus of the poor is declining over time, their future role and contribution for poverty reduction and livelihoods might also decline significantly. As ICRISAT develops its long-term strategy for SAT agriculture, there are several key questions that need to be addressed. What are the alternative futures and outlooks for dryland commodities under changing population and income growth scenarios? What kinds of policies are required to counter the potential impacts of water scarcity, land degradation and climatic variability and to accelerate sustainable intensification and diversification of agriculture in the SAT? What is the potential impact of changing consumption patterns and growing preferences for rice, wheat and maize and livestock products on the production, supply and trade opportunities for dryland commodities? This necessitates careful analyses of future outlooks and plausible futures for dryland commodities.

Based on the recommendation of the previous socio-economic CCER for ICRISAT to strengthen its strategic research and to continue to scan and monitor changes in the wider SAT environment, ICRISAT in collaboration with IFPRI has initiated a joint project to assess the alternative futures for SAT agriculture.

Objectives: Examine detailed scenarios, and project plausible futures for dryland agriculture and the potential impacts that global economic and environmental changes will have on dryland agriculture.

Methodology: The extended version of the global food and water policy modeling framework of IMPACT-WATER is being used to explore the future outlooks for dryland crops and gain useful foresights about alternative adaptation and investment strategies. The model explicitly introduces dryland crops (sorghum, millets, chickpea, pigeonpea and groundnut) along with a complete set of other crop and livestock commodities into the global food and water models which allows a more realistic simulation of cross-commodity price and income effects. In response to certain policy scenarios, the model allows supply, demand for different uses (food, feed, and other), and prices to be determined within each country and regional sub-models and linked at the global level through trade. The model also projects area, production and yield trends for each country, sub-region and at the global level.

Main Findings & Policy Implications:

Sorghum: When the historical trends over the last four decades are examined, the area of this crop has been declining globally but increasing slowly in all sub-regions of sub-Saharan Africa (SSA), and North Africa and West Asia (WANA). The global area of sorghum declined from 50 million ha in the late 1960s to about 44 million ha in the recent past (2003-2005). The harvested area declined gradually in South Asia, North America, and South America. Despite the global decline in area cultivated, production of sorghum has been growing over the last four decades. Global production has increased from 40 million t in the early 1960s to about 58 million t during the last three years (2003-05). Yields in China for example have increased from less than 1 t/ha to over 4 t/ha. Unfortunately, no such transformation has taken place in other developing regions (SSA, South Asia and WANA). Yields in these areas remain very low (less than 1 t/ha) and generally stagnated or even declined in some areas. While a slight positive trend is evident in South Asia (since the late 1980s) and SSA (since the late 1990s), sorghum yields declined in the WANA region. The positive yield growth rates for South Asia and SSA indicate that new varieties (including hybrids in Asia) are beginning to have a visible effect on production. The low yields in the two regions however mean that much more needs to be done in making sorghum production in these areas economically attractive to small producers. The IMPACT projections under the business-as-usual scenario to 2025 (compared to the 2000 baseline) indicate that similar trends would continue globally. Sorghum area is projected to increase in the ASARECA regions (ECA) from 8 to 10 million ha, in the SADC region from about 0.85 to 1.12 million ha, in Western and Central Africa (WCA) from about 13 to 16.5 million ha, and in South Asia decline from 10.3 million to about 8.5 million ha.

Millets: The overall trend in area of millets is similar to that of sorghum. The harvested area declined gradually in all regions except in SSA and WANA, which explains the decline in the global area of the crop. The global area declined from 43 million ha in the early 1960s to about 35 million ha in the last three years (2003-2005). The area of the crop declined in South Asia, China and transition economies (Ukraine and Russia). Despite the increase in production in the 1960s from 25 million to over 30 million t, the overall pattern in global production has also largely stagnated around 27 million t since the early 1970s, indicating that the declining area has not been offset by growth in yields in the major growing regions. Millet yields in China have doubled (from about 1 t/ha to 2 t/ha). Yields also doubled in South Asia where it started from a low base of 0.4 t/ha to about 0.8 t/ha. The lowest increase comes from SSA which accounts for over half of the global crop area - yields have improved marginally from about 0.5 t/ha to about 0.6 t/ha over the period of four decades. However, there is an evident upward trend in the yield of millets in SSA and South which offers some hope for improving food security and incomes to smallholder farmers in the dry tropics. The IMPACT base model projections to 2025 by region show the following trends: in ECA the area will increase from about 3.5 to 4.6 million ha, in SADC from 0.83 to 1.1 million ha, in WCA from 15.7 to about 20 million ha, and in South Asia decline from about 13.5 to 11.2 million ha.

Groundnut: The global area of groundnuts registered a substantial increase over the last four decades from about 15 million ha in the early 1960s to over 25 million at the turn of the 21 century. Like wise production has also increased from less than 15 million t to over 35 million t. The crop area expansion is more evident in China and lately in all sub-regions of SSA, but declined in South America partly because of competition from soybean as a source of meal and oils. The trend in South Asia is not so clear; despite the variability over the last few decades, groundnut area in South Asia seems to be on a slightly upward trend. While groundnut also remains important in the USA, the area of the crop seems to have reached a long term stable equilibrium around 0.5 million ha. When we look at trends in yields, there seems to be a growing trend in all regions. The most dramatic increases have occurred in the USA and China where yields have increased from less than 1.5 t/ha in the early 1960s to over 3.5 t/ha and about 3 t/ha at the turn of the century. Yields are lowest in all sub-regions of SSA where a marginal increase from 0.6 t/ha to 0.7 t/ha had taken place. The yields in South Asia started from a low base similar to SSA, but gradually increased to about 1 t/ha in the last few years. The IMPACT projections to 2025 show that the area of groundnut would increase in ECA from 2.42 to 3.42 million ha, in the SADC from 1.05 to 1.26 million ha, in WCA from 6.2 to 8.9 million ha, but decline in South Asia from 7.30 to about 7 million ha. The area in China will however increase from 4.7 to 5.2 million ha. Increasing trends are also projected for Myanmar and Indonesia.

<u>Chickpea:</u> The global area of chickpea has declined from about 12 million ha in the early 1960s to about 10 million ha at the beginning of the 21st century. This is mainly due to the gradual decline in the area of the crop in the major growing region of South Asia. However, there has been slight growth in WANA, ESA, Canada and Australia over the last decade. The growth rate in global production shows an overall positive trend, but production has not increased substantially partly because of the extreme variability in global supplies in the 1980s and 1990s and partly due to the slow growth in yields in South Asia where much of the crop area is concentrated and where the crop area registered a declining trend. Yields have doubled in Central America (mainly Mexico) from about 0.8t/ha to 1.6t/ha, which has enhanced the competitiveness of Kabuli chickpea from this region in international markets. Yields have improved gradually in South Asia (mainly India) and in SE Asia (mainly Myanmar). Despite the expansion in area, chickpea yields largely stagnated around 0.6t/ha or even declined in eastern and southern Africa and WANA. While yields are relatively higher in Australia and Canada, incidence of diseases like Ascocyta blight had led to extreme variability or even declining trends. The IMPACT base model projections to 2025 show that in ECA the area will increase from 0.35 to 0.60 million ha, in the SADC from about 0.1 to 0.17 million ha, and in WANA from 0.9 to 1.3 million ha, but decline in South Asia from 7.8 to about 7 million ha.

<u>Pigeonpea:</u> Unlike sorghum, millets and chickpea, the global area for pigeonpea has shown a significant increase during the last four decades. The area of the crop increased from 2.5 million ha in the early 1960s to over 4.5 million ha at the turn of the 21st century. This increase in area was registered in all regions. In India, the crop has found a niche in the rice-wheat fallows as short duration varieties that can be grown in rotation with cereals have been introduced. The crop has also gained popularity among smallholders in Eastern and Southern Africa. The growing export demand from South Asia (mainly India) seems to have triggered interest among dryland farmers to grow the drought tolerant and multipurpose crop. While yield has increased gradually as a result of adoption of new varieties in all regions, average yields remain very low, ranging between 0.6t/ha to 0.8t/ha. Over the last two decades, global production of pigeonpea has more than doubled from about 1.5 million to over 3 million t, the combined effect of area expansion and yield growth. The IMPACT base model projections to 2015 show that in ECA the area will increase from about 0.3 to 0.5 million ha, in the SADC from about 0.13 ha to 0.20 million ha, and in South Asia from 3.90 to 4.20 million ha.

1D.6. Methodology to analyze impact of technological and policy interventions for micro-watershed in Semi-Arid India: A bioeconomic modeling approach (Asia)

The overall objective of the study is to develop a methodology to analyze the possible impacts of technology change and policy incentives on household welfare and the sustainability of the natural resource base in the SAT regions. The previous impact studies of watershed development in India have hardly ever integrated the biophysical factors with economic factors to assess the complementarities and the tradeoffs within the framework of farm household economic behavior. So it is important to apply a holistic and integrated approach like bio-economic modeling to simultaneously assess and evaluate impact of watershed development on the welfare of the poor and the natural resource conditions at a micro level and also to identify effective policy instruments and institutional needs for enhancing the effectiveness of the watershed approach. The benchmark watershed in Kothapally village, Ranga Reddy district, Andhra Pradesh is selected as the study region because of the unique availability of both biophysical and socioeconomic data covering a period of 5-6 years. The data provides an opportunity to integrate both biophysical and socioeconomic data to develop a bioeconomic model to study simultaneously the impact of the technological and policy interventions on household welfare and quality of the natural resource base in the watershed.

The baseline model serves as a starting point for policy experiments to assess the likely impact of alternative policy intervention. The bioeconomic model used in the study analyses the combined effects of land degradation, population growth and market imperfections on household production, welfare and food security.

Collaborating Institutions and Scientists:
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ICRISAT : B Shiferaw, SP Wani, TK Sreedevi

1D.7. Development of a dynamic non-linear bioeconomic model with crop-livestock integration (Asia)

Bioeconomic models are useful tools in policy analysis because they can reflect the biophysical as well as socioeconomic conditions essential for decision making with in specific "bioeconomy". They may be used to explore the linkages between ecology and the economy and the dynamic effects of these linkages over time. In this study a watershed level dynamic non-linear bioeconomic model with crop-livestock integration is developed for the Kothapally watershed. This model maximizes the income of the whole watershed, which include three types of households based on land endowment (small, medium, large), who are spatially disaggregated into six different segment in the watershed landscape [three types of soils based on soil depth (shallow, medium and deep) and two types of land (dryland and irrigated land)]. The model maximizes the aggregate net present value of income of the watershed over a 10 year planning horizon. The income of the household groups is defined as the present value of future income earned from different livelihood sources (like crop, livestock, non-farm, etc) subject to constraints on level, quality and distribution of key production factors (e.g., land, labour, capital, bullock power, soil depth), animal feed requirement and minimum subsistence food requirements for the consumers in each household group.

The crop production in the model is affected by change in soil depth, which is reducing due to soil erosion. The erosion level in the watershed is estimated for predicted land use pattern and through transition equation soil erosion reduces the initial soil depth of the land. By using econometric method the yield-soil depth response is estimated and used in the production function in the bioeconomic model. The nutrient balance in the watershed is estimated by using a nutrient balance equation in the model. This equation estimates the nutrient balances for the simulation period based on inflow (fertilizer and manure application, biological fixation and atmospheric deposition) and outflow (crop grains and residual yield, erosion and leaching) of nutrients in the watershed.

The baseline model serves as a starting point for policy experiments to assess the likely impact of alternative policy intervention. The bioeconomic model used in the study analyses the combined effects of land degradation, population growth and market imperfections on household production, welfare and food security.

The study, which is a Ph.D dissertation, concludes that increases in the price of dryland crops and increasing the yield of the dryland crops by introduction of some high yielding drought tolerance varieties can be effective technological and policy instruments for slowing down the process of land degradation and improve the welfare of the farmers in the watershed. The results from the Kothapally watershed study should be useful to policymakers and others seeking to reduce poverty and improve land management in SAT regions of India. This model can also be used as a decision support tool to develop an optimum farm plan for different households in the watershed with available resource without affecting the natural resource base. Beyond this, the bioeconomic modeling approach used in this study can be usefully adapted and applied in many other settings.

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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 topologies 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 by 2009. Developments shared annually with partners.

MTP Output Target 2006: Alternative institutional topologies for adoption of technological and market innovations reported

1E.1. Social exclusion and gender surveys executed and reported

Social exclusion and gender surveys executed and reported

Social exclusion and gender surveys were completed as part of the study on “gender and social capital mediated technology uptake” and published as Impact Series 12. This study explores gender-differentiated benefits from the social capital buildup in technology uptake, and the decision-making patterns of men and women with respect to production, consumption and household tasks; and allocation of resources. The background research examined women’s role in developing social capital, and research developed a case study of the groundnut producing areas of Maharashtra in western India, and compared ‘with’ and ‘without’ technology situations, and ‘before’ and ‘after’ situations in relation to the package of groundnut production technology introduced in the region in 1987. The paper addresses three aspects: (1) social networks in technology adoption, (2) the gender-based activity pattern, and (3) build-up of social capital leading to improvements in the welfare of farmers and the farming community with a gender perspective. Available evidence suggests substantial differences in networks of men and women, particularly in composition. The evidence suggests that men belong to more formal networks reflecting their employment or occupation status, while women have more informal networks that are centered on family and kin. Findings show that women who are engaged in agriculture and allied activities develop bonding social capital characterized by strong bonds such as that found among family members or among members of an ethnic group. Men who are engaged in agriculture, on the other hand, develop bridging social capital characterized by weaker, less dense but more crosscutting ties such as with farmers, acquaintances, friends from different ethnic groups and friends of friends. Women’s employment opportunities significantly improved with the introduction of technology. Finally, the study concludes that while technology development and exchange can build upon social capital as a means of empowering women, much more needs to be learned about the approaches that foster build-up of social capital.

1E.2. Architecture of social networks in SAT villages documented

Evolution and returns to social networks (Asia)

Earlier case studies at ICRISAT on Groundnut Production Technology (GPT) uptake systematically documented the process by which farmers – both men and women - as well as the whole community became empowered through the build-up of social capital which facilitated access to resources, information and technology. The build-up of social capital played an important role in influencing impacts from the technology because of the ways in which social networks and social relationships facilitated technology dissemination. Gender-based social analysis revealed the dynamic interplay between individuals within households and institutions, the evolving relationships and access, allocation and control of resources.

The differing social networks and correspondingly different levels of access to information, led to men and women experiencing different consequences. Networks facilitated communication, coordination, and the provision of information/knowledge regarding agricultural production, income generation, skill enhancement and food security of the family. The study highlighted that social networks played a crucial mediating role in the process of technology uptake.

Appealing to the concept of social capital as networks and relationships, new research is proposed that will examine the types of social networks that marginalized groups associate with, the networks that the powerful groups have access to, and the relationship between the two groups. Establishing the network architecture (including networks developed either through formal organizations, kinship groups, neighborhoods networks, work groups, self-help groups, or informal interactions), it is proposed to look into the role of social networks and power relations in the village in ensuring any risk and poverty reducing impacts of particular programs / interventions apart from the role of mutual support networks in risk management by poor rural households, including via migration or other strategies. Using an HIV/AIDS lens in research on the dynamics of shocks (HIV/AIDS), the research will also look into which communities, families and individuals are best able to minimize the damage due to HIV/AIDS and why? How can social networks help in coping with this shock?

By creating social networks within the community among the landless, the vulnerable, and tribals both men and women and linkage with the external agencies especially the market, it is envisioned to create more opportunities for the vulnerable community and empower them. As the networks are developed there are more resources available to the communities, which will lead to an improvement in the well being of rural marginalized communities and thus bring them into the mainstream of development. Acknowledging the role of social capital in the nexus of technology exchange/interventions presents both substantial challenges and opportunities to understand the complex gender relationships.

Social networks – sociological and theoretical perspectives

The needs of different populations (whether defined by gender, age, ethnicity, or some other criterion) in areas such as agriculture, health, employment, and education are not exactly the same, and policy interventions developed to meet these needs are the most effective when they are sensitive to, and incorporate, the values and aspirations of a target population. This requires that policy be based on an accurate understanding of the ways in which the cultural (in the broadest sense) characteristics of a particular population influence the relationships that its members have with other fields or domains within the wider society. The study of social networks is important since it helps us to better understand how and why we interact with each other, as well as how technology can alter this interaction.

From the review of literature it can be summarized that while some theorists looked at social networks as an explanation of how norm consensus and norm directed behavior was achieved, the others saw profit-maximization as the goal of individual actors while interacting with others.

Essentially, network analysis focuses on patterns of relations between actors. Both relations and actors can be defined in many ways, depending on the substantive area of inquiry. For example, network analysis has been used to study the structure of affective links between persons, flows of commodities between organizations, shared members between social movement organizations, and shared needles between drug users. What is central is an emphasis on the structure of relationships, which serves to link micro- and macro-level processes.

Social network analysis has emerged as a key technique in modern sociology, anthropology, social psychology and organizational studies, as well as a popular topic of speculation and study. Though network analysis is an interdisciplinary endeavor, its roots can be found in classical anthropology and sociology. Research in a number of academic fields have demonstrated that social networks operate on many levels, from families up to the level of nations, and play a critical role in determining the way problems are solved, organizations are run, and the degree to which individuals succeed in achieving their goals.

Collaborating Institutions and Scientists:

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Social networks and safety nets: village-level perspectives (Asia)

The study on social networks using the VLS commenced in 2005. Village level pilot surveys were conducted in four villages of Aurepalle, Dokur, Shirapur and Kanzara villages to elicit information on the social groups and networks existing in the village. The questionnaires implemented were on social networks with emphasis on existing village organizations and development activities in the village including the beneficiaries of these activities. Complementary informal discussions and focus group meetings revealed that if social networks are to be successfully harnessed to implement policy or alter existing behaviour of members within the network, then it is important to understand the dynamics of the uptake of the new products and activities. Household level or individual level questionnaires were also piloted for a more in-depth inquiry on membership in organizations, credit, support and share cropping networks, information networks, income transfers and collective action and exclusion. It was noted that analysis of the network architecture and linkages among public programmes and informal networks need further inquiry to gain more complete understanding of how social networks may help or hinder policy interventions and change.

Collaborating Institutions and Scientists:

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ICRISAT	: KPC Rao, MCS Bantilan, R Padmaja

1E.3. Multi-sectoral approach to address HIV and AIDS implemented

Multi-sectoral approach to address HIV and AIDS

In the context of the HIV epidemic increasing in the semi arid tropics (SAT) and causing the rural SAT to be further marginalized, ICRISAT is initiating a multi-sectoral and partnership based initiative to mainstream HIV/AIDS in its research agenda.

This study aims to understand and clarify less understood aspects of the relationship between livelihoods, food insecurity and HIV/AIDS. A set of six case studies is planned to examine the dynamics of risk behavior and the spread of the HIV epidemic. This paper gives initial insights and key findings from this initiative in Bhongir and also throws light on preliminary observations made from the reconnaissance visit in Kolar, Karnataka.

The initial analysis and readings of the ethnographic data present unique dimension to the way HIV/AIDS have been perceived and this paves the way to look at the connections between HIV/AIDS, rural livelihoods and agriculture. Majority of the people who were tested are involved in agricultural labor or owned lands and cultivated. A majority of these people from agricultural background, who visited VCTC even though they were not tested to be HIV positive suffered from STDs. There remains many questions, some of which may be answered with the quantitative analysis and some may require in depth ethnographic study. The questions that arise are: What are the migratory patterns of these men and women. How do they tap the sex network in the city in which they migrate and what are the local sex networks. Since most of them are temporary migrants who come back to the village after working in the cities, what facilities can be made or how can technology innovations including agricultural and NRM interventions be harnessed to improve their livelihoods, create a strong income and asset base to cope with the disease and provide additional and supplementary nutrition. The case studies thus pave the way for further in depth analysis of the HIV – poverty –rural livelihood linkages, to better understand the gaps in order to enable targeted interventions.

1E.4. Options for targeting technology interventions for HIV/AIDS affected households defined (2006)

Several studies have been conducted on targeting technology interventions for HIV/AIDS to improve rural livelihoods within the agricultural sector:

- Seed Systems and HIV and AIDS Impacts
- HIV and AIDS impact mitigation: convergence of short-term humanitarian and longer-term development interventions
- Harnessing Social Capital for HIV and AIDS Impact Mitigation: Implications for Agricultural Technology Targeting
- Scaling out agricultural technologies to HIV and AIDS orphaned and vulnerable children
- Mainstreaming HIV/AIDS and gender in the challenge program Water for Food project in the Limpopo river basin

<u>Objectives:</u> The overall objective was to understand the impacts and to inform research and development policy both at ICRISAT and for partners in the process of designing and implementing effective technology delivery systems for scaling up/out.

<u>Main findings and policy implications:</u>

<u>Seed systems:</u> Commodity-specific extension by the private sector (NASFAM) contributed significantly to the transfer of information and knowledge on seed particularly for crops with relatively high market value within generations. The two main inter-generational pathways utilised focused on interventions involving kinship ties particularly grandparents through involvement and teaching-by-doing. The alternative pathway utilised formal schools as institutions.

<u>Action research and short-term versus long-term interventions:</u> Action Research will be useful across the short-term, transition and long-term phases. In the short-term, AR should be applied to Aid the targeting process and to specifically identify entry points into communities. It should further be utilised to set priorities upon which the transition phase will build.

<u>Social capital in HIV and AIDS impact mitigation:</u> Two main forms of social capital were most useful to the communities: community-based networks and meso-level formal organizations working with the communities. The implication is that agricultural development and research institutions need to engage formal and informal community-based networks and the health sector in addressing the effects of HIV and AIDS.

<u>Scaling out of agricultural technologies:</u> The study recommended that for interventions that offer direct gains to orphaned and vulnerable children to succeed, several important issues ought to be considered: understand the socio-demographic characteristics of the communities; inclusive beneficiary targeting process; the choice of project interventions based on proper appraisal and targeting; and stronger partnerships and synergies with formal and informal local networks.

Scaling out of agricultural technologies: This ongoing piece of work uses qualitative and quantitative approaches using formal and informal surveys to cover key issues on gender and health along with adoption and adaptation of crop varieties and management practices, soil fertility enhancement, soil and water management and conservation, institutional arrangements and access to information and to input and output markets. A paper on HIV/AIDS and gender mainstreaming was presented in the CPWFP1 inception workshop in Polokwane, South Africa.

1E.5. Searching for appropriate institutional arrangements for common watershed management in the semi-arid tropics in India

In the present student research the main question is "Which institutional alternatives enable a successful implementation of watershed projects in villages in the semi-arid tropics?" A watershed implementation is seen as successful if: 1) villagers appreciate the implementation process; 2) villagers received some direct or indirect benefits; 3) the watershed community organizations founded during the implementation process will sustain even when the implementation process will be completed.

According to the theoretical framework it is argued that the main reasons for the lack of success in watershed projects are coordination failures between local actors/appropriators (collective action problems). To overcome such coordination failures three different institutional alternatives are discussed: a) the market approach; b) the central government c) community governance.

In the course of the research project three watershed villages, Dokur, Sripuram and Zainallypuram, in the Mahaboobnagar district were analyzed to understand the impact the three above mentioned institutional alternatives had on the success of the watershed implementation process in the concerning villages. For the data collection 137 household interviews, 8 key-person interviews and 3 focus group meetings were conducted.

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ICRISAT: KPC Rao, MCS Bantilan

Funding : H.Wilhelm-Schaumann- Foundation, Hamburg, Germany.

1E.6. Collective action and property rights for poverty reduction in watersheds

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 at 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 LCA. 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

1E.7. Guidelines for more effective implementation and monitoring of drought relief programs drafted and disseminated by 2005/6

Improving the Efficiency of Relief Seed (ESA)

Whereas markets can be enhanced to offer opportunities for the poor to move out of poverty, the nature of SAT production systems indicates that a significant proportion of households would not be in a position to benefit significantly from market-led interventions alone. This includes the chronically poor and vulnerable households in marginal and remote locations, as well as households under transitory emergencies. In addition, evidence suggests that HIV/AIDS may be contributing to an increase in the proportion of rural populations trapped in such chronic food insecurity and poverty. To achieve sustainable food security, many of these households require sustained access to agricultural innovations in addition to the type of agricultural assistance more usually supported under emergency interventions.

Past ICRISAT research also revealed that most farmers only received access to new varieties of sorghum and pearl millet through relief seed programs. Commercial interest in the multiplication and sale of these seed crops was closely linked with the pursuit of tenders for the supply of relief seed. By the same token, questions began to emerge about the quality of this seed and the impacts of its distribution. ICRISAT was asked to help assess relief seed programs in Zimbabwe in order to identify ways to improve their payoffs.

Objectives: 1. Assess strategies for the supply of relief seed to small-scale farmers in drought prone environments.
2. Assess quality constraints apparent in some relief seed, and propose strategies for resolving quality problems.

Methodology: Led a review of the quality of relief seed in partnership with ICRISAT breeders and national regulatory authorities. Multiple surveys have examined the need for and payoffs to relief seed distribution. Further surveys are examining alternative voucher based strategies for the supply of relief seed and other agricultural inputs.

Main findings & policy implications: We estimate that at least 50% of the seed internationally traded in southern Africa is headed for relief programs in one country or another. This includes virtually all of the seed trade for secondary food crops such as sorghum, pearl millet, groundnut, and cowpea. Relief seed commonly accounts for 15 to 70 percent of national seed trade depending on the year, and the size of both government and donor programs.

Despite this, ICRISAT research has consistently shown that relief seed needs tend to be over-estimated. Farmers are remarkably good at saving their seed even after severe drought. And community seed systems are reasonably good at facilitating trade from seed surplus to deficit households after natural disasters. In this context, farmers look to relief programs as means to gain access to new varieties, or to seed they might otherwise want to purchase (e.g. for hybrid maize). By corollary, the impacts of relief seed on household food security and incomes tend to be small. We could find no evidence that the distribution of relief seed contributes to an increase in crop area planted. Rather, this tends to displace seed that might have been otherwise obtained from alternative sources – either own stocks or the village market. The relief seed industry remains strong, in part, because farmers have been conditioned to claim they have no seed in order to qualify for free handouts (and food aid). Also, seed companies see these programs as an opportunity to sell large lots while avoiding the costs of wholesale and retail trade. And relief seed handouts are an easy solution for NGOs.

ICRISAT was asked to sample the quality of relief seed lots being distributed in Zimbabwe after evidence of the past distribution of poor quality sorghum and groundnut seed. Two years of sampling revealed common problems of low genetic purity and poor germination. These studies are highlighted the poor quality of labeling of most relief seed which makes it difficult to hold companies responsible. While the majority of seed tested was of adequate quality, some of this seed undoubtedly worsened the food security of recipient households. ICRISAT drafted a protocol ultimately adopted by FAO in Zimbabwe, and all major seed companies trading in the country, to improve relief seed quality and labeling. A national review of this problem resulted in a series of recommendations for regulatory and practical reform designed to minimize this problem in the future. These stand as an example for all countries in southern Africa.

These economic research results have been used to argue against the direct distribution of free seed to small-scale farmers. These programs undermine investments in wholesale and retail seed trade. In fact, there has been an increase in the number of seed companies in southern Africa with no retail trading networks. Rather, these new companies aim simply to pursue a shifting array of tenders for relief seed in various countries in the region. In order to qualify for these tenders, many cut corners, buying grain for sale as seed. Our research has clearly diagnosed these constraints provided a warning to NGOs and donors to pursue stricter criteria on their tenders.

ICRISAT research is also encouraging the testing of alternative voucher based strategies for seed distribution. This started with a review of seed fairs, an increasingly common strategy being promoted (in part by ICRISAT) throughout eastern and southern Africa. The study revealed that contrary to common assumption, seed fairs do not necessarily strengthen local markets, but may undermine these markets. They contribute to seed price inflation. While seed fairs are suppose to provide farmers a broader choice of seed varieties to purchase, this choice is often constrained by how the market is organized. Seed fairs may be justified if commercially available varieties commonly distributed through free handouts are poorly adapted to the agro-ecology targeted by the relief program. But they unjustifiably undermine local and commercial markets where adapted varieties are available.

ICRISAT has responded by encouraging more experimentation with vouchers redeemable for a choice of seed (and other agricultural inputs) from retail shops. Initial research here has proved promising, though difficult in the context of Zimbabwe's hyperinflation.

Economic Analysis of Alternative Seed Delivery Systems for Agricultural Recovery Programs in Zimbabwe

Background: Recurrent droughts in Zimbabwe have often led to loss of food production and the subsequent need for recovery. Seed has traditionally been donated to smallholder farmers struggling to recover from drought as a surest way of ensuring that households immediately start up crop production. However, there is now growing debate on the rationale for seed aid, because vulnerable communities are unable to withstand even small disasters and their farming systems have remained less resilient despite the continued supply of free seed. More attention is now placed on adoption of seed fairs as an alternative to direct free seed distribution under relief and recovery programs in Zimbabwe

Objectives: The major objective of the study was to methodologically assess whether seed fairs offer broader positive impacts compared to direct seed distribution. The study carried out a comparative analysis of seed utilization, crop diversity and the cost effectiveness of direct seed distribution and relief inputs delivered through seed fairs. Data for the study was obtained from ICRISAT surveys carried out during seed fair implementation and post planting period for households that participated either in seed fairs or recipients of direct seed distribution in eight districts of Zimbabwe.

Main Findings and Policy Implications: The results of the study showed that contrary to expectation, crop and variety diversity was not enhanced, *a priori*, by the seed fair approach. Farmers obtaining seed through direct distribution planted more crop types and a smaller portion of their land to maize. Though a lot of diversity was offered at seed fairs, this did not transfer into production. However, farmers who acquired seed through seed fairs planted most of the relief seed they acquired, in fact seed fair beneficiaries planted 26 percent more in terms of the proportion of the relief seed they received compared to farmers who were not given a choice. On cost effectiveness of alternative relief input delivery systems, the cheapest means to distribute seed to needy households appears to be the option of using seed fairs. In effect neighbouring farmers were redistributing stocks of local seed to deficit households. This approach is almost 40 percent cheaper than the next best alternative of direct distribution of commercially supplied seed. The major constraint of community –sourced seed is that, it might not be available in large quantities and high quality hybrid seed cannot be provided from the community. However, the analysis could not conclude that direct distribution is inherently bad because it is important in delivering commercial seed and ensuring that large quantities of seed are available.

In supporting local livelihoods systems, seed fairs, *de facto* lay the immediate ground for moving away from outside or external assistance and link relief and development aims from the early stages of a crisis. Policy makers should encourage seed fairs as a way of strengthening local seed markets and for distributing community seed whereas direct seed distribution will complement this effort by providing commercially sourced seed. Seller organized seed fairs coordinated by extension and local leadership can be created to ensure sustainable and reliable markets of local seed and this could also save buyers on the search cost of seed.

1E.8. Provision of public goods through participatory planning: an experimental exploration of the deliberative process

Rural areas in developing countries mostly suffer from a dramatic underprovision of public goods. The widespread failure of central governments in meeting peoples' demand led to a debate on the respective advantages and risks of privatization and regulation, but a third option still needs to be seriously analyzed: locally-based collective action to mobilize financial resources and local labour. This research project aims at evaluating the potential of village meetings to mobilize collective action for the provision of local public goods, in heterogeneous communities of rural India. Through variants of the public good game that will be played in the ICRISAT villages, there is a plan to assess in which measure the possibility of deliberation facilitates the realization of outcomes that are closer to the social optimum rather than the inefficient Nash equilibrium. The weight of caste/income/gender inequality and social norms on the possibility of achieving higher social efficiency throughout the deliberative process will be measured. The results could provide interesting suggestions for policy improvements regarding the organization and delivery of responsibilities to *Gram Sabhas* (GS), the grassroot institutions of decentralized economic planning according to the Indian Constitution.

Preliminary interviews in three VLS villages of Dokur (Mahboobnagar district in Andhra Pradesh), Shirapur and Kalman (Sholapur district of Maharastra) were carried out to collect information regarding functioning and performance of local Gram Panchayat (GP), tax collection and the need for public meetings in the villages. Individuals were asked whether they performed any activity for the welfare of the village, especially as volunteers, and whether they participated in public meetings (formal or informal) where matters of public interest were discussed. The aim was to collect their perceptions on how decision-making was carried on in the village on matters that regarded groups of people or the entire village population, to understand if they had the option of participating in decision making, and to learn more about interaction and power balance between people of different castes. Direct evidence on the amount of taxation that is locally extracted and the money saved through voluntary labour in collective activities for cleaning and maintaining village infrastructure was collected.

Documentation obtained in Maharashtra villages:

Annual state of accounts for 2005-06 of Shirapur and Kalman's Panchayats with taxes collected by Gram Sevaks, governmental transfers received, and public expenses in the villages;
Amount of taxation collected by Talathis for the State Revenue Department in Shirapur and Kalman, in financial year 2005-06;
Official registration and minutes of Gram Sabhas conducted in Shirapur and Kalman in 2006;
Estimate of value of voluntary work provided by citizens of Kalman in 2002 during two weeks of activities to clean the village (Sant Gadhge Baba Gram-Swachyta Abhiyan)

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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 by 2009 with associated capacity building for partners and policy makers in SAT Asia. New knowledge generated annually will be shared with partners.

MTP Output Target 2006: VLS partners consortium developed and initiated for future joint efforts on research to determine socio-economic mobility, agricultural and rural transformation

1F.1. Microlevel assessments of shifting livelihood strategies in the rural SAT using VLS approach in India ongoing

Rural households have become more nucleated and the average family size declined from 8.37 to 5.10 over the past 25 years. The literacy levels have improved sharply, particularly in case of women. The occupational structure has become more diversified. Both the ownership and operational holdings have become much smaller due to population pressure and sub-division of holdings. The incidence of poverty declined over the last twenty five years but still 35 per cent of the sample households live below the poverty line. The average per capita income is Rs. 6286 ($ 145) per year. Despite increases in income and consumption levels, still more than one half of the households are calorie deficient while about one-fourth of the households are protein-deficient.

Cropping patterns changed significantly in favor of cash crops. But farmers are unable to recover the costs in case of both food and cash crops on the rainfed lands. The crops which received irrigation support have yielded positive net returns mainly because of subsidies. Even in case of livestock, the returns over variable costs are quite meager. Despite low returns from crop and livestock enterprises, the net household incomes have increased due to higher contributions from non-farm sources, caste occupations, migration and other minor sources. Self-help groups of women are able to contribute to family incomes.

Farmers invested heavily on water exploration but under-invested on soil and water conservation. Most of the farmers displayed risk aversion and showed interest in purchasing well-designed rainfall insurance schemes. The rural households participated in the development and welfare programs of the government. A household, on an average, received a benefit of Rs. 4288 over the 17 years period (1995-2002). Despite these programs, a substantial proportion of labor force is indulging in seasonal migration in search of work and livelihood.

1F.2. First and second generation VLS data bases integrated and documented through tracking surveys

One of the objectives of the Second Generation VLS (2001-07) was to establish comparability with the OLD-VLS (1975-84) sample. A systematic tracking survey was initiated in 2005 and continued in 2006. A lot of changes occurred in the demographic profile of sample villages between 1984 and 2005. Out of the 1998 individuals present in the sample households during first generation VLS, 432 persons died during the two decades period. 675 individuals migrated out of the village. Quite a few of them were the young women who moved out after their marriage with a person belonging to other village/town/city. But a considerable number of individuals have also moved out of the village in search of work. Many of them are seasonal migrants who come back to the village at least for some months in a year. Some of them have migrated permanently as they expect to get better opportunities for livelihood, employment and income. The remaining 857 members continued to stay in the village. Only 581 of them were included in the sample for second generation VLS during 2001-05. For a comparative analysis of the livelihoods, it is necessary to include the migrants and the people residing in the village but was not included in the sample. A two-pronged approach was used to establish comparability between the samples of the first and second generation VLS. The size of the sample was enhanced from 446 to 592 households. All the split-offs from the original households were added to the sample since 2005-06 in order to cover most of the individuals from the original sample. The results of tracking survey are presented in the table below.

Tracking and attrition

Status by 2005	Full sample of individuals included in 1975-1984 with tracking information in 2005	Of which: Included in the 2001 survey, i.e. in the village and in the sample in 2001	Of which: Not included in the 2001 survey.
Dead by 2005	432	24	408
Migrated by 2005	675	45	630
In village by 2005	857	581	276
No information by 2005	34	4	30
Total	1998	654	1344

Efforts were also made to collect information from the migrants who visit the villages for festivals, annual get-to-gathers and other social occasions. In case of the migrants who do not come back to the villages, a special survey was conducted to collect data from migrants residing outside the village. With the limited funds available, migrants staying in the villages near by to the VLS villages and those who are living around Hyderabad city were interviewed. Even after a great effort to locate the migrants, some could not be reached as they have moved to a new place by the time we try to contact them at their old address known to the people in the VLS villages. We are continuing our efforts to track them and elicit their responses to the questions designed for the purpose of the study.

Migration Survey

Status of individuals	Total
1. Total no.of migrants	858
2. No.of individuals interviewed	431
3. Individuals not available	90
4. Individuals to be interviewed	337

When we included the migrants and split-offs from the original households in the sample, the average incomes of the households increased substantially. Since the migrants typically included those who received better wages and settled in the service and the business sectors of the economy, their inclusion in the sample increased the income levels. The migrants are also better educated and have a better asset endowment. There are substantial transfers of money from the migrants and their family members living in the villages.

1F.3. Partnerships for policy and development strategies with US-universities

Progress on US-universities linkages

Renewal of partnership with US Universities stimulated interest among researchers and analysts from universities including students. It met with an enthusiastic response from more partners who developed proposals for undertaking VLS based studies. This includes 5 students for summer internship in 2006.
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 like 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. This is a clear evidence of the external use, adoption or influence of this International Public Good by partners, stakeholders and clients.

Collaborating Institutions and Scientists:
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Felix Naschold Purdue University : Kathryn Boys
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Research scholars and their research areas are-

Martina Pignatti Morano - Provision of public goods through participatory planning: an experimental exploration of the deliberative process
Andreas Gramzow – Policy measures to improve rural livelihoods in India
Christina M Nyhus – The effects of major crop commodities on iron intake in rural India (1972 – 2002)
Reena Badiani – Migration
Kathryn Boys – Poverty dynamics
Ammad Bahalim – Impact of trade liberalization

Exploring the dynamics of poverty in India's Semi Arid tropics

The general trends which were found to be of particular relevance to the visited communities are issues related to water scarcity, urbanization, and globalization. Also crucial recent village transformation is the decreased interest in the agriculture, due to the lower potential for profits in this sector.

Overall it would seem that the welfare of households in the villages of Aurepalle and Dokur has increased since the last VLS iteration. It is impossible to draw any conclusions on the basis of such a short visit and limited number of observations. Through these visits one, however, is left with the general impression that income and access to public goods has improved, and that income disparity has not increased and potentially may be decreasing.

While poverty rates are useful indicators of the level of poverty in a country during a specific period of time, they do not provide the information concerning the extent of mobility in and out of poverty or about the length of time people remain in poverty. The degree and cause of poverty experienced by individuals and households has important policy implications, but is frequently masked by data aggregation and dependence upon stylized 'facts'.

The purpose of this study is to compliment and extend previous work on trends in poverty and income distribution. By more closely examining the dynamics of poverty, one can explore which types of households stay longest below the poverty threshold and whether certain changes in household status are associated with transitions into or out of poverty.

<u>Conclusions:</u> Results suggest this analytical approach can offer useful insight into poverty dynamics. Differences exist in the type of events correlated with entry, exit and duration of poverty spells. Suggest alternative policies needed to remedy each 'phase' of poverty. Results suggest policies may be more effective at preventing entry into poverty than facilitating exit or shortening duration. 'Medium Term' poverty appears to be correlated with different events than long and short term poverty. Further consideration of issue needed

<u>Collaborating Institutions and Scientists:</u>

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ICRISAT	: MCS Bantilan, KPC Rao

Migration in the VLS : The missing link

The paper focuses predominantly on permanent migration; temporary migration in the context of trends in the VLS. Within the VLS villages, income and consumption has risen significantly between 1975-1984 and 2001-2004. The preliminary data has shown that the migrants differ from non-migrants in salient socio-economic characteristics. Without data on the standard of living of migrants, attrition bias is likely to be substantial. The impact of migration on consumption and income trends is likely to be a function of the reason for migration; whilst the size and direction of the bias can be estimated as a function of observable characteristics for some migrant populations (notably those migrating for work), for other migrant populations (including migrants for marital reasons or those repatriating with family) estimates of attrition bias using currently available data are likely to be inaccurate. By tracking migrants, the VLS has taken a step forward to understanding better the nature of poverty and income dynamics.

From a policy perspective, migration is increasingly being seen as an important livelihood option for poorer groups, and as a means of poverty reduction (Deshingkar, 2005). The data on migration will help us to better evaluate the alternative frameworks within which migration has been placed. Migration has been posited to take a myriad of different forms: as a coping mechanism (Bantilan and Anupama, 2002), as an income diversification strategy (i.e. a long term plan, a permanent strategy to diversify income in the village) or as a permanent route out of poverty (i.e. permanent migration out of the village). Whilst econometrically the full identification of the different mechanisms would not be possible given that the sample consists of only six villages, from a more qualitative perspective the data will give us insight into the different forces driving migration

Migration in the VLS – how to study it?

Migrant tracking was planned in three main phases. The first phase was to prepare the surveys and to pilot test the new modules. The first phase was coordinated to coincide with a festival in one of the villages to ensure that questions could be pre-tested on both temporary and permanent migrants (both of whom are likely to return at festival time). The second phase involved an incubation period of 6 months during the period of festivals in the village, to capture all migrants who returned to the villages. The third phase entailed finding the migrants at their current place of residence.

The preliminary data has shown that the migrants are different in salient socio-economic characteristics. Most notably, migrants can be identified by age, sex and educational attainment. Since educational attainment is likely to be linked to unobservable ability and innovation, and has also been shown to contribute directly to income growth (Mankiw et al, 1992), it is likely that the consumption and income trends for these individuals is different from those who have stayed in the village. Very little is currently know about the migrants for non-marital purposes, who make up over half of those who have migrated, since we are unable to judge the size of the attrition bias for these individuals due to the nature of migration; the new data will fill this lacuna.

In addition, much can be said for the impact of migration, in particular temporary or seasonal migration, at a village level. For example, it would be interesting to study whether the decision to migrate has an impact of child nutrition (Hildebrandt 2005) or child enrolment in educational institutions. McKenzie and Rappaport (2002) study the impact of migration on educational attainment in Mexico; they find that the low-skilled migration flows to the US have a negative impact on the number of years of schooling attained in given areas. Another pertinent research question is the impact of migration on technology adoption – do migrants act as an information flow, bringing knowledge and new technology home with them?

In ICRISAT, much has been done to ensure that the VLS dataset continues to expand in a methodologically sound manner. Ensuring that all further split-offs are included in the village level surveys will allow the VLS dataset to incorporate the dynamic elements of household formation, as well as ensuring that attrition bias is reduced to a minimum. The tracking of migrants that is currently in taking the concept of reducing attrition bias one step further, by providing a truly comprehensive data set.

Collaborating Institutions and Scientists:
Yale University : Reena Badiani
Oxford University : Stefan Dercon
ICRISAT : KPC Rao, MCS Bantilan

Village Level Impacts of Trade liberalization: A look at Dokur

This paper is intended to be a village level analysis of trade liberalization. Methodological questions were raised and data collection methods will be analyzed. The tenuous causal linkages between macro-level trade policy and micro-level village impacts ought to be critically analyzed to determine in what manner current theoretical frameworks are being extended. By using integrated regional and national commodity markets for common crops some have translated relative price changes directly into village level analysis including impact on income, employment, and migration. How is this meaningful? What social indicators ought to be reviewed? What are some questions and conclusions that current analysis poses?

Conclusion: Kuiper and van Tongeren (2005) is perhaps the most robust model in the literature examined. Current literature on village level impact analysis, at least amongst economists concerned with trade, are developing new models that are more robust but also more real. Issues such as missing markets, imperfect markets, or inadequate access to markets hinders the level of analysis given current data. New realms to explore would include more complex analyses of social indicators such as the HDI. However, on the whole devising tools that look beyond macro-level growth would give policy makers and scholars better insight into impacts, furthering the decision making process.

Collaborating Institutions and Scientists:
Cornell University : Ammad Naeem Bahalim
ICRISAT : KPC Rao, MCS Bantilan

The effects of major crop commodities on iron intake in rural India (1972 – 2002)

This research proposes to understand how the Green Revolution (GR), the agricultural programs which tripled rice and wheat yields, affected iron intakes in India from 1983 until 2002. Although food balance sheets show overall iron densities of available foods decreasing in South Asia during the period of the GR, it is not well understood what foods contributed to this decline and how this translated into dietary intakes among different segments of the population. A side effect of the sole promotion of rice crops was the concurrent decrease in per capita production of pulses (beans, lentils, chickpeas, etc.), which are relatively rich in iron, given the predominantly vegetarian diet. The specific aims of the project are to (1) describe trends in dietary intake of iron in the rural Indian diet over the past 20 years and (2) investigate the effects of prices as well as individual and household-level characteristics on iron intakes in rural India from 1983 to 2002.

Methodology: Using secondary data of the National Nutrition Monitoring Board (NNMB) and the ICRISAT District Level Database, trends in dietary intakes for iron as well as major agricultural commodities in the Indian population over the last twenty years will be analyzed.

1F.4. Nutrition orientation in agricultural research-ICRISAT perspectives (Asia)

Despite the considerable progress made in crop production in recent decades, many developing countries still fall short of the goal of providing adequate food and nutrition. While some countries in south Asia achieved food self-sufficiency through the green revolution, ensuring equitable access to food still eludes them. With over two billion people globally subsisting on diets that lack the essential vitamins and minerals required for normal growth and development, access to food and combating this "hidden hunger" continue to pose a serious challenge in south Asia. The paper entitled, " Food and nutrition security- perspectives on nutritional orientation, access and strategies" presents a background of the challenge facing the global community - ie, food and nutrition security, now one of the Millennium Development Goals (MDG). It analyses the prevailing food production and availability scenario in south Asia, the nutrition orientation in agricultural research, and policies to enable access to and affordability of food by the poor and vulnerable. This is discussed in the context of a strategy to reduce malnutrition and enable rural households to improve family health in sustainable ways. ICRISAT's perspective on nutrition through biofortification of coarse cereals and legumes (eg, zinc and iron in sorghum and millets; and vitamin A in groundnut) and minimization of aflatoxin contamination are highlighted. Strategic approaches are discussed to broaden the interpretation of the MDG challenge on food and nutritional security to include economic, physical and social dimensions not only at the national level but also at the individual level of children, women and men.

1F.5. Livelihood insecurities in the 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 for the epidemic. 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 Semi Arid Tropics 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 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

1F.6. Strategic analysis of alternative futures for dryland agriculture

Dynamics, challenges and priorities for dryland agriculture (Global)

The marginalization of the dryland region of Asia and sub-Saharan Africa is reflected in the pervasiveness of poverty and continuing concerns about malnutrition, growing constraints of the natural resource base (water scarcity and land degradation), lack of infrastructure, poor dissemination of improved technologies and further economic liberalization. Dryland ecosystems, where most of the world's poor live, are characterized by extreme rainfall variability, recurrent but unpredictable droughts, high temperatures and low soil fertility. Indeed, dryland areas present significant constraints to intensive agriculture. But despite extreme conditions, agriculture and related land use have always played a leading role in dryland economies and societies. Even as they are constrained by limited water and soil resources, optimization of these resources is often a matter of survival for dryland rural economies (FAO 1999).

The Green Revolution of the 1960s and 1970s, with its package of improved seeds, farm technology, enhanced irrigation and chemical fertilizers, was highly successful in meeting the primary objective of increasing crop yields and augmenting aggregate food supplies. In Asia and parts of North Africa, where the package was most widely adopted, food production increased substantially during those decades. Despite its success in increasing aggregate food supply, the Green Revolution as a development approach has not necessarily translated into benefits for the lower strata of the rural poor in terms of greater food security or greater economic opportunity and well-being. It bypassed many areas with large numbers of rural poor (Freebairn, 1995, Pachico et al., 2000, Evenson and Gollin, 2003). In particular, vast expanses of dryland regions were bypassed by the Green Revolution. They have failed to attract investments in agricultural technology among smallholders as well as among the commercial sector due to small or non-existent markets. So far, the policy regimes have favored the irrigated regions and failed to address the continuing marginalization of the drylands. Past policies on drylands have failed in another respect: they focused primarily on the presumed limitations of the natural resource base rather than on the people, their knowledge, skills and capacity for innovation in overcoming or circumventing environmental constraints (Anderson et.al, 2003).

Recognizing the need to reach the poor in marginal environments, development planners and policymakers are increasingly eyeing less-favored dryland regions, where agricultural transformation is yet to take off. The issues of equity, efficiency and sustainability compels the need for improving the productivity of dryland agriculture given that the growth opportunities in irrigated areas are slowly being exhausted. A well-targeted approach is sought to address the neglected rural dryland areas that are yet to benefit from improvements in agricultural technology and policy.

The study on the "Dynamics, challenges and priorities for dryland agriculture" summarizes the major challenges in achieving food security, income growth, poverty reduction and environmental sustainability, and identifies future strategies and priorities for dryland agriculture in Asia and sub-Saharan Africa. It highlights emerging issues that threaten the sustainability of agriculture and future sources of growth. The paper presents an overview of the dynamics of dryland agriculture followed by an analysis of the persistent challenges facing it, and identifies opportunities such as income diversification, market and rural/urban linkages, institutional innovations, private sector investments, trade liberalization and commercial orientation of agriculture. Implications for policy, research priorities and development pathways are drawn, followed by a vision for Asian and sub-Saharan Africa dryland agriculture.

Collaborating Institutions and Scientists:

SEARCA	: Balisacan, Arsenio
ICRISAT	: WD Dar, MCS Bantilan, P Anand Babu, KV Anupama, H Deepthi, R Padmaja

1F.7. Policy study on vulnerability and rainfall insurance

Rainfall insurance in India: How it can help farmers

The agricultural survey on rainfall insurance, which was commenced in 2004 in collaboration with the World Bank, has been completed in February, 2005. Quality data was validated and ensured. A supplementary mini-survey was conducted in June-July, 2005. This canvassed information from all the 1060 households in the sample from a simple one-page schedule. The data entry were completed by August 2005. The data allowed analysis of the sources of risk, effects and strategies of farmers; the adverse impact of government policies on rainfed farmers; and policy implications.

Crop insurance is a major public policy designed to get at the source of the problem of yield variability. It is a contingency contract where participant farmers pay premium and collect indemnities when yields fall below an insured level. In India, crop insurance was introduced in mid-1980s as crop loan insurance, where the insurer covers a percentage of the loan for annual cultivation expenses of the participant farmer. As the crop loan insurance is largely tied to the institutional loans, it benefited the farmers with irrigation to a major extent.

Research carried out through the ICRISAT village level studies suggested that rainfall lotteries are better than the crop insurance schemes to diminish rural household income variability in a cost-effective manner in rainfed areas of India (Walker and Ryan, 1990). They would be a fair betting system and would be open to all households in the village. For instance, if landless labor households felt the demand for their labor was markedly reduced in low rainfall years, they could hedge their future labor income by purchasing tickets on the lowest or what they perceive to be the most adverse rainfall event. Rainfall may explain more of the variation in crop revenue when compared with the pure impact of yield variability as it also influences the area sown.

How can rainfall insurance help rainfed farmers? The facts presented in this policy brief imply viable policy initiatives to help rainfed farmers face risks inherent in rainfed agriculture. Rainfed farmers have very little access to institutional credit as they are subjected to credit rationing by the institutions due to high-perceived risks. Hence they do not get much cover from the National Agricultural Insurance Scheme (NAIS), which focuses primarily on crop loan insurance. Well-designed rainfall insurance products can attract rainfed farmers to buy the policies and get adequate insurance coverage. At the moment, while the NAIS charges lower premium than the actuarial levels (particularly in the case of food crops and oilseeds), the rainfall insurance premiums charged by the ICICI Lombard or Agricultural Insurance Company of India are actuarial. The difference creates a disincentive to rainfed farmers, resulting to slow uptake rates. There is a compelling justification for subsidizing the premium for rainfall insurance products so that they get a level playing field in matters of insurance. To introduce the rainfall insurance concept to a wider clientele of smallholders, institutional arrangements facilitated by pilot programs can show how best insurance scheme benefits them. It can also feature the benefits to a wide range of beneficiaries including landless households and small producers in the rainfed regions. Ultimately, a well designed and appropriately subsidized rainfall insurance scheme will enhance the uptake rates and will improve the safety net against weather-induced risks, especially among the marginalized population who are dependent on rains for their livelihoods.

A policy brief based on the above findings has been published and disseminated to stimulate policy dialogue.

Collaborating Institutions and Scientists:
World Bank : Xavier Gine, Donald Larson
ICRISAT : KPC Rao, MCS Bantilan, D Kumara Charyulu

1F.8. PRA on information flows and new technologies to enable intensification completed

Participatory rural appraisal report in 4 villages of Western Niger (WCA)

Methodology: This report is a description of potential changes in livelihood strategies and out-comes as perceived by farmers in 4 villages where the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) collected a longitudinal data from 1982 to 1987 in Niger. Participatory rural approaches were used to examine the potential drivers of agricultural transformation in the villages. Uptake of modern technologies (seed, fertilizers and other inputs), income diversification, farm and non-farm growth linkages, market and institutional development were discussed with farmers' groups using PRA tools.

Results: Livelihood assets and technologies: PRA findings show that village assets and infrastructure have marginally increased in high rainfall zones (600-800 mm rainfall) of Gobery and Fabidji but have decreased in low rainfall zone (400 mm rainfall) such as village Sadeizi Koira. Access to clean water has improved as a result of NGO or rural project intervention but remains insufficient to satisfy the high demand due to population growth. There has been little changes in the types of crops grown, cropping systems and technological practices by farmers during the last 25 years. The use of modern technologies remains limited despite numerous efforts at developing and disseminating modern technologies by R&D institutions. There is virtually no systematic use of modern sorghum or pearl millet varieties, fertilizers and other inputs such as fungicides, insecticides and pesticides. However, the use of animal traction is one of the most significant break-throughs. Many more households own animal traction equipment especially in the more favorable rainfall areas. In low rainfall zones, farmers are complaining of loss of some varieties and crops due to the shortening of crop cycle and repeated droughts. The identification of constraints to uptake of modern technologies remains a major challenge for national and international research and development institutions. The potential losses in bio-diversity need to be proven as well as its impact on productivity and resilience. Research and development interventions likely to enhance agricultural productivity are essential.

Livestock: Livestock rearing is practiced in all the 4 villages surveyed. The extensive mode remains the most common and livestock is entrusted to shepherds who go in transhumance to look for grazing land. However, during the last 25 years, population density and subsequent reductions of grazing areas are forcing households to move into semi-intensive modes of livestock rearing. Livestock fattening is practiced by both men and women to different degrees depending on the village. In the less favorable zone of Samari and Sadeizi Koira, women are more involved in livestock fattening than men whereas in the average favorable area of Gobery and Fabidji, both genders equally take part on this activity. Small ruminants constitute a households store of value or savings schemes and are often used to smooth households' consumption so as to ensure food security especially during production risk fail-ures or to finance social events such as marriages. According to groups of farmers, during the last 25 years, livestock density has decreased mainly due repeated droughts (1973 and 1984) and low stocking rates on diminishing grazing areas. However, while cattle stocks owned have decreased per capita many more households own small ruminants such as sheep and goats. Households own more livestock in the low rainfall zone of Sadeizi Koira and Samari than the high rain-fall area of Gobery and Fabidji. Farmers are claiming that the share of income from livestock is higher than that of crops in the low rainfall zone than else. Crop-livestock interactions are stronger in the low rainfall zone than the high rainfall area. There is a need to develop crop and production technologies that will in-crease the supply of feed resources. There is also need to identify and develop institutions and policies that will enhance the development of the livestock sector especially in the low rainfall areas.

Income diversification: Income diversification is a strategy used by households to cope with climatic, production and price risks. Income diversification strategies change according to agro-climatic zone. In Gobery and Fabidji, the presence of the *dallol* (with assured water) has provided opportunities to farmers to diversify within the agricultural sector especially into vegetable production especially during off-seasons. In addition, farmers have also well diversified much into the secondary and tertiary sectors mainly due to market opportunities offered by their proximities to a large market: Fabidji. Processing, handicrafts, short and long-distance trading for livestock or natron exporters, cereal trade, and a range of petty jobs such as groundnut oil processing, vegetable sales, handicrafts are also well developed. Whereas in low rainfall areas of Samari and Sadeizi Koira, there are few opportunities to diversify within the agricultural sector due to poor climatic conditions.

Farmers are diversifying outside the sector. Long distance trading of wood, cowpea haulms or millet stalks and migration are the main survival strategies. In all the villages surveyed, income diversification options have changed in response to the development of markets opportunities, better use of resources (i.e. water in the *dallol*), or low returns to agricultural labor. There is a need to identify household income diversification strategies and the necessary policy, institutions and technological changes that would affect the rural non-farm economy and translate these into research and development interventions that generate employment and reduce poverty.

Migration: Migration is practiced in all the 4 villages but its importance in improving livelihood outcomes varies by agro-climatic zone. There is short or long, seasonal or permanent migration. In Gobery and Fabidji, migration tends to move from seasonal to even permanent. It is practiced mostly by the young men in the households. According to groups of farmers interviewed, at least 1 out 3 households in the 2 villages has at least one member in temporary or permanent migration. Revenues from the migration are shared within the households and are partially used for investment or consumption purposes. In the low endowed areas of Sadeizi Koira and Samari, migration is a major survival strategy. Every year, at least one member of the household is engaged on seasonal migration. Revenues from migration are mainly used to secure household food security. Both men and women migrate. Migration patterns have not changed much during the last 25 years but their intensity and importance in livelihood strategy has significantly increased. The returns to migration, optimal migration pathways and its impact on agricultural production and rural livelihoods should be well investigated.

Farmers' organizations and markets: During the last 25 years, in all the villages, institutional build-up has improved as a result of NGOs or rural development projects who have invested in building farmers' organizations. Farmers are often organized around socio-professional groups with different socio-cultural and economic interests. In Samari, farmers have organized committees to help resolve a range of socio-economic problems that would otherwise involve high transaction costs. The role and impact of these institutions in economic development is not well researched. During the last 25 years, there has been a poor development of input and product markets despite market liberalization in the 1980s and currency devaluation in 1994. Except in Samari where a new market has emerged, in Sadeizi Koira, no market has been developed. In Gobery, the market created some 50 years has not expanded much but the market transactions in Fabidji have expanded considerably. Similarly, market frequencies have not changed and remain weekly mar-kets. Although all villages are connected to a set of markets, these markets are far away from those villages, thereby increasing trading costs except in Fabidji where transaction costs are low and market transactions have increased considerably. In Gobery, Fabidji and Samari, there are market niches for vegetable crops. Farmers report poor access to and availability of essential inputs such as seed of modern varieties or fertilizers. The role of markets in agricultural transformation needs to be well researched.

1F.9. Policy brief on changes in rural livelihood strategies and outcomes in West and Central Africa (Niger and Burkina Faso)

<u>Poverty dynamics and development pathways (WCA)</u>

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 entry is currently completed. Data documentation, exploration and analysis are forthcoming.

Project 2
Sustaining biodiversity of Sorghum, Pearl Millet, Small Millets, Groundnut, Pigeonpea and Chickpea for current and future generations

Output A: Germplasm of staple crops assembled and conserved and an additional 5% of germplasm characterized annually and documented for utilization

MTP Output Targets 2006:
- *500 new sorghum accessions from USA*
- *Unrestricted access to and movement of staple crop germplasm ensured*
- *Germplasm accessions regenerated for longterm conservation and distribution (at Patancheru genebank)*
- *Safety copy of germplasm at Niamey genebank conserved and regenerated as appropriate (groundnut 2,000 accessions and pearl millet 5,000 accessions)*

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 ICARDA were compared and 500 accessions including wild relatives were identified as unique for inclusion in the genebank. Similarly, we identified from the chickpea collection maintained at WSU, Pullman, USA 839 accessions as unique for ICRISAT. The chickpea germplasm collections maintained at National Centre for Plant Genetic Resources of Ukraine (NCPGRU), Ukraine were compared with our collection and identified 313 accessions as unique for inclusion in our collection.

HD Upadhyaya

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

Milestone A.1.1.3: Sorghum germplasm from USDA (500 no's), 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 483 germplasm samples of sorghum received from Niger for growing in Post Entry Quarantine Isolation area (PEQIA) for observation and subsequent release. We are awaiting import permits from the Government of India for acquiring pearl millet (424) collections from Niger and pigeonpea (231) collections from Tanzania, Uganda and Mozambique presently held at Niamey and Nairobi genebanks, respectively.

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 was compared and identified 2,708 accessions of Rockefeller collection that were missing from our collection. A set of 619 accessions from the newly identified set of 2708 accessions, was received from NSSL and added to the collection. We are making efforts for obtaining the rest of the identified material for filling the existing gaps in the collection.

The germplasm database of Chinese Academy of Agricultural Sciences (CAAS), China was compared with our database and identified 250 accessions of sorghum belonging to race Caudatum and subrace Kaoliang and 250 accessions of groundnut germplasm belonging to botanical variety hirsuta as unique for ICRISAT genebank.

HD Upadhyaya

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

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)

Recording data on 483 sorghum accessions originating from Niger is in progress in PEQIA. NBPGR, India released a total of 839 chickpea germplasm samples provided by the Washington State University, Pullman, USA that were identified as unique for ICRISAT genebank. From this set, we planted 747 cultivated types during the post-rainy season of 2006 for recording morpho-agronomic traits and seed increase. Seed samples of 62 (annual types) out of 70 wild chickpea seed samples from this set are planted in a glasshouse under extended light for seed increase. We received 622-groundnut germplasm samples for further inspection and release by NBPGR. These accessions were identified as unique from the national collections of groundnut maintained at National Institute of Agricultural sciences (NIAS), Japan.

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 no's) characterized (HDU/CLLG, 2009)

We are awaiting import permits from the Government of India for acquiring pearl millet (424) collections from Niger and pigeonpea (231) collections from Tanzania, Uganda and Mozambique presently held at Niamey and Nairobi genebanks, respectively.

HD Upadhyaya and CLL Gowda

A total of 123 pigeonpea landraces collected from farmers' fields in four pigeonpea growing regions of Tanzania were characterized and evaluated for 16 qualitative and 14 quantitative descriptors; and their response across three pigeonpea growing environments in Tanzania and Kenya determined. Polymorphism in the qualitative traits was relatively low among accessions and across collection regions. Collections from the northern highlands exhibited lower diversity in qualitative descriptors, especially physical grain characters, relative to the other three regions, an indication of farmer selection in response to market preferences. There were significant differences in agronomic traits among accessions and in G x E interaction. Grain yield had positive significant correlations with pods per plant, pod yield, racemes per plant and both primary and secondary branches per plant, traits that were also correlated with plant height. High broad-sense heritability was recorded for days to flower, days to maturity, plant height, raceme number and 100 seed mass. Principal component analysis separated variability among landraces according to days to flower, days to maturity, plant height, number of primary and secondary branches, and number of racemes per plant. Similarly, cluster analysis separated the accessions into six groups based on the same traits. There was close clustering within and between materials from the coastal zone, eastern plains and southern plains with the northern accessions distinctly separated and with wide dispersion within them. Overall, two diversity clusters were evident with coastal, eastern and southern landraces in one diversity cluster and northern highlands landraces in another cluster. This diversity grouping established potential heterotic groups in this pigeonpea germplasm, which may be used in crosses to generate new cultivars adapted to different pigeonpea growing environments with consumer acceptability. The grouping may also form a basis of forming a core collection of this germplasm representing the variability available in Tanzania.

S Silim and E Manyasa

Milestone A.2.1.3: Morphoagronomical 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)

420 cultivated and 84 wild entries were planted at 3 sowing dates (22/06 and 22/07 at ICRISAT Samanko Station, 2006/07 in IER Sotuba Station) to measure the phenological characters with 8 individuals to represent one entry per replication and 2 replications per sowing date. The seedling emergence was good for cultivated sorghums and more heterogeneous for wild/weedy sorghums due to seed dormancy. Twelve thousand plants

were measured for 15 quantitative characters whereas qualitative morphological traits were measured at the entry level on one plant in each replication. The racial identification showed that guinea gambicum (53%), guinea margaritiferum (16%) and the sweet sorghums belonging to the bicolor race (12%) are the dominant sorghum groups in Mali. The highest variation was observed for cycle duration (sowing-flag leaf emergence duration varying from 48 days to 122 days). Most of landraces are partially or completely photoperiod sensitive. Stay green is mainly explained by the date of flowering rather than other environmental factors with late maturing varieties keeping green leaves longer. The information provided by SSR and DArT markers on the same material, combined with the observed quantitative trait variability within the 3 dominant sorghum groups in Mali, should allow for promising genetic association studies.

F Sagnard and PS Traoré (in collaboration with IER)

Milestone A.2.1.4: Morphoagronomical 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)

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)

Chickpea:

Drought tolerant lines: Twenty accessions selected during 2004-2005 season for root depth, a trait related to drought in chickpea were evaluated with four control cultivars (Annigeri, ICC 4958, ICCV 2, ICC 12237) for yield potential and other agronomic traits in a replicated trial. Among the deep-rooted accessions ICC 1356 (3555 kg ha^{-1}) produced 36.9 % greater seed yield than the drought tolerant control ICC 4958 (2596 kg ha^{-1}) and 27.4% greater seed yield than the highest yielding control cultivar Annigeri (2790 kg ha^{-1}). Similarly, ICC 1431 (2967 kg ha^{-1}) and ICC 95 (3124 kg ha^{-1}) produced 14.3% and 20.3% higher seed yield than ICC 4958 and 6.3% and 12.0% higher seed yield than Annigeri, respectively.

In another experiment with 20 accessions selected during 2004-2005 season for root length density, another trait related to drought in chickpea were evaluated with four control cultivars (Annigeri, ICC 4958, ICCV 2, ICC 12237) for yield potential and other agronomic traits in a replicated trial. Among the accessions with largest root length density, ICC 13816 (3120 kg ha^{-1}) produced seed yield similar to the drought tolerant control ICC 4958 (3095 kg ha^{-1}) and the highest yielding control cultivar Annigeri (3230 kg ha^{-1}).

Large-seeded Kabuli Types: Evaluated 34 large-seeded kabuli chickpea accessions originating from diverse geographical regions with four control cultivars (ICCV 2, KAK 2, JGK 1, L 550) in a replicated trial. ICC 14214 (2063 kg ha^{-1}; 53 g 100-seed weight) produced 7.1% greater seed yield and 35.1% higher seed weight than the large seeded and high yielding control cultivar KAK 2 (1927 kg ha^{-1}; 39 g 100-seed weight). Similarly, ICC 6243 (2359 kg ha^{-1}; 38 g 100-seed weight) and ICC 16803 (2072 kg ha^{-1}; 40 g 100-seed weight) produced 7.5 to 22.4% higher seed yields with similar seed weight to KAK 2. ICC 6210 (1925 kg ha^{-1}; 48 g 100-seed weight), ICC 7347 (1943 kg ha^{-1}; 51 g 100-seed weight), and ICC 14203 (1921 kg ha^{-1}; 56 g 100-seed weight) produced similar seed yield with 23.1-45.6% greater seed weight than KAK 2.

Evaluated 16 large-seeded kabuli chickpea accessions, selected from newly assembled accessions, with four control cultivars (ICCV 2, KAK 2, JGK 1, L 550), in another experiment. ICC 17457 (2468.2 kg ha^{-1}; 54.5g 100-seed weight) and ICC 17458 (2216 kg ha-1; 47g 100-seed weight) produced 28.0% and 14.9% greater seed yield with 47.3% and 28.1% greater 100-seed weight than the large seeded and high yielding control cultivar KAK 2 (1929 kg ha^{-1}; 37 g 100-seed weight).

Early Maturing Lines: Seventeen early-maturing germplasm accessions and three control cultivars (ICCV 2, Annigeri, ICCV 96029) were evaluated in a replicated yield trial for seed yield related agronomic traits. ICC 16347 (91 days; 1751 kg ha^{-1}) matured earlier and produced similar seed yield as the early-maturing control ICCV 2 (97 days; 1772 kg ha^{-1}). ICCs 5829, 11916, 13925, and 14368 (1962 – 2434 kg $ha^{-1;}$ 100 days) produced 10.7% to 37.4% greater seed yield and matured similar to ICCV 2.

Extra-Early Kabuli Types: Evaluated 58 elite extra-early maturing kabuli germplasm lines and four control cultivars (KAK 2, L 550, ICCV 2, JGK 1) under normal and late sown environments. Under normal sown environment two entries (2130 – 2327 kg ha^{-1}) produced higher seed yield, flowered earlier (30-33 days), matured in similar days (96-97 days) with similar seed size (38–39 g) to high-yielding large-seeded control cultivar KAK 2 (2016 kg ha^{-1}; 36 days flowering; 97 days to maturity; 37 g 100-seed weight). One of these two also produced (1212 kg ha^{-1}) higher seed yield and took similar days to flowering and maturity with similar seed size to control KAK 2 (904 kg ha^{-1}) under late planted conditions.

Salinity Tolerant: Evaluated 52 salinity tolerant chickpea germplasm accessions with ICCV 2 and salinity tolerant control cultivar Jumbo 2. ICCs 4953, 5003, 10552, 10575, 12339, 13124, and 14595 and ICCV 95311 (3023–3678 kg ha^{-1}) produced significantly greater seed yield than ICCV 2 (2147 kg ha^{-1}) and Jumbo 2 (2089 kg ha^{-1}).

Evaluation of Newly Assembled Germplasm: Evaluating 747 newly assembled chickpea germplasm accessions from USA and five control cultivars in an Augmented design trial during 2006-2007. Data recording is in progress.
500 accessions from ICRISAT genebank and 418 accessions from ICARDA genebank are being evaluated with five control cultivars in an Augmented design trial during 2006-2007. Data recording is in progress.

Pigeonpea:
Evaluated 1000 accessions with four control cultivars (ICP 6971, ICP 7221, ICP 8863, ICP 11543) in an augmented design trial. The preliminary analysis indicate that ICPs 15391, 15014, 15012, 15021, and 16335 (50-54 days) were early flowering, ICPs 14459, 10915, 10904, 10906, and 10914 (41-49 cm) were short statured and ideal for mechanical harvesting, ICPs 7952, 9450, 9558, 2372, and 14225 (183–235) were with higher number of racemes, ICPs 9450, 4167, 11970, 14225, and 7952 (423–471) had higher number of pods plant per plant, ICPs 7035, 12825, 12746, 7407, and 13799 (19 – 23 g 100-seed weight) had large-sized seeds. ICPs 7952, 11737, 1, 13203, and 13483 (240–270 g yield plant^{-1}) were high yielding accessions. Harvest index was higher in ICPs 8835, 1209, 2624, 3602, and 11605 (50%- 65%).

Groundnut:
Drought Tolerant: Eighteen germplasm accessions with high SPAD and low SLA, the traits related to drought tolerance (Upadhyaya, 2005) were evaluated for pod yield and other traits related to yield in a replicated trial. Eight accessions (3.49–4.43 t ha^{-1}) produced higher pod yields than the control cultivar ICGS 76 (3.46 t ha^{-1}). ICGs 6766 and 14475 (3.49–3.83 t ha^{-1}) produced higher seed yield with greater seed size (71-83g) and similar shelling percentage (67-70%) to the control ICGS 76. (66g 100-seed weight; 70% shelling).

Evaluated 960 accessions in augmented design with four control cultivars (Gangapuri, M 13, ICGS 44, ICGS 76). Among the sub sp. *hypogaea* 274 entries (2.80–4.19 t ha^{-1}) produce higher pod yields than the control ICGS 76 (2.69 t ha^{-1}) and 249 entries (2.80–4.19 t ha^{-1}) produced higher pod yield than control cultivar M 13 (2.78 t ha^{-1}). ICGs 8795 (4.19 t ha^{-1}) and 9116 (3.84 t ha^{-1}) were significantly better than both the controls. Among the sub sp. *fastigiata* 32 entries (3.23–4.0 t ha^{-1}) produced significantly greater pod yields than the high yielding control ICGS 44 (2.19 t ha^{-1}). ICGs 1561, 2272, 11285 and ICGVs 04075 and 01276 (3.50-4.0 t ha^{-1}) were the top five entries.

Pearl Millet:
1000 accessions are being evaluated with three control cultivars, IP 3616, IP 17862, IP 22281, in augmented design trial during 2006. Data recording is in progress.

HD Upadhyaya and CLL Gowda

Characterized 360 early to medium maturity pearl millet landraces for agro-morphological traits and grain yield in rainy season 2006 at six locations in Senegal, Mali, Burkina Faso, Niger and Nigeria, and data made available to NARS partners. 64 late-maturing pearl millet landraces characterized for agro-morphological traits and grain yield in rainy season 2006 at three locations in Senegal, Mali, and Niger, and data made available to NARS partners. Preliminary characterization of 280 pearl millet landraces published in the International Sorghum and Millet Newsletter (47:110-112). The global pearl millet core collection was grown in a replicated trial at the ICRISAT Sahelian Center near Niamey, Niger, in the Rainy Season 2006. Ms Jenny Coral Padilla, MSc student from University of Hohenheim, Stuttgart, Germany, was involved in the characterization. Data analysis and MSc thesis write-up are underway.

BIG Haussmann

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

In chickpea, we characterized 500 accessions for plant pigmentation and days to 50% flowering. In groundnut, over 2000 accessions were characterized for updating 30 traits in the databases. In sorghum, 385 accessions for which data was missing for days to 50% flowering and plant height were characterized during 2006 rainy season. We characterized during 2005-2006 post-rainy season, 235 sorghum germplasm accessions representing zerazeras and composite collections, for which data on important morpho-agronomic characters was incomplete. A total of 512 pearl millet accessions planted during 2005 post-rainy were characterized for four traits (days to 50% flowering, plant height, panicle length, panicle thickness). In pigeonpea, characterized 640 accessions during 2005 rainy season for which characterization data was incomplete and a total of 866 accessions were planted for characterization during 2006 rainy season for collecting data on missing traits.

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)

Identification of new germplasm sources for resistance to diseases: Two hundred and fifty new germplasm accessions were evaluated for resistance to ascochyta blight (AB), botrytis gray mold (BGM), dry root rot (DRR) and collar rot (CR) diseases under controlled environment conditions and for fusarium wilt (FW) under artificial epiphytotic conditions at ICRISAT-Patancheru. Standardized individual screening techniques were employed to evaluate these accessions for individual diseases. Severities of AB, BGM and DRR were scored on 1-9 rating scale and the incidence of FW and CR was presented as percentage of mortality.

Resistance to AB: High level of resistance to AB were not identified in any the accessions evaluated, however, eight accessions, ICCs 643, 1052, 1069, 1093, 1903, 1915, 2114 and 2142 were found moderately resistant (3.1 to 5 rating) to AB.

Resistance to BGM: Among these new accessions, 30 had moderately resistant (3.1 to 5 rating) reaction and rest were found susceptible.

Resistance to DRR: Of the 250 new accessions evaluated for DRR resistance, two accessions ICCs 562 and 1600 had resistant reaction (3 rating) and 76 accessions were found moderately resistant (3.1 to 5 rating).

Resistance to CR: Resistance to CR was not observed in any of the accessions evaluated. Hence our quest continued to identify resistant sources in the germplasm and breeding material.

Multiple disease resistance in new germplasm: No line was found resistant to all the four diseases tested. Only one accession ICC 1915 was found to be moderately resistant to AB and DRR. Ten accessions ICCs 153, 1229, 1360, 1419, 1422, 1560, 1837, 2113, 2118 and 2202 had moderate resistance (3.1to 5 rating on 1-9 rating scale) to BGM and DRR.

70 elite germplasm accessions are being screened in wilt sick-plot during 2006-2007. Data recording is in progress.

S Pande, HD Upadhyaya and CLL Gowda

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

Identified 33 vegetable type pigeonpea accessions for further verification and evaluation. We are also testing a few more accessions for higher seed number per pod.

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)

In the 2006 postrainy season, 2268 accessions of sorghum were grown for regeneration. This includes, 128 accessions for diversity, 632 critical accessions for conservation as active collection and distribution and 1466 accessions for long-term conservation. For pearl millet, a total of 887 accessions were planted in the post rainy season for long-term conservation (806 accessions) and medium-term conservation (81 accessions). In pigeonpea, planted a total of 922 accessions during the rainy season for long-term conservation (599 accessions) and medium-term conservation (323 accessions). In addition, we also planted a set of 146 mini core accessions of pigeonpea for conservation and utilization. In groundnut, during the rainy season, we planted for regeneration of global mini core (184 accessions), Asia mini core (60 accessions), and critical accessions of groundnut (209 accessions) for medium-term conservation and utilization. During the post-rainy season, a total of 1671 accessions of groundnut were planted for long-term conservation (1308 accessions) and medium-term conservation (363 accessions). In chickpea 2139 accessions were regenerated. A total of 374 critical accessions representing chickpea (68), pigeonpea (12), groundnut (283 including 110 wild relatives), and small millets (12) were regenerated in the glasshouse and special facilities.

HD Upadhyaya

The global pearl millet core collection (504 accessions and four control cultivars) was grown in a replicated trial at the ICRISAT Sahelian Center near Niamey, Niger, in the rainy Season 2006. Ms Jenny Coral Padilla, MSc student from University of Hohenheim, Stuttgart, Germany, was involved in the characterization. Data analysis and MSc thesis write-up are underway.

BIG Haussmann

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 2006, we tested the seed viability of 7032 accessions. This included 2416 (pearl millet-981; chickpea-635; pigeonpea-376; and groundnut-424) accessions processed as active collection and 1452 (pearl millet-787; chickpea-418; and pigeonpea-247) accessions processed as base collection. Germplasm seed samples with viability above 85% were processed as base collection. The mean seed viability of germplasm ranged between 86.6 for groundnut and 99.0% for chickpea.

For safety back up, we prepared a set of 1470 groundnut accessions harvested from a special regeneration (2005 rainy season). The seed viability in this material ranged between 92-100% with mean 99.9 %. For monitoring seed viability of conserved germplasm, we tested the seed viability of a total of 3146 (sorghum-2264 and chickpea- 882) accessions conserved as active collection for different periods. The viability ranged between 56 and 100% with a mean of 95.6% in chickpea and between 71 and 100% with a mean of 95.7% in sorghum. Similarly, 1396 accessions of groundnut base collection for more than 10 years in storage were monitored and the viability ranged between 46 and 100% with a mean of 94.0 %. This exercise has resulted in the identification of 47 accessions of chickpea and 11 accessions of sorghum from active collection and 69 accessions of groundnut from base collection as critical for regeneration during 2007.

HD Upadhyaya and RP Thakur

Seed health testing of germplasm accessions for the medium- and long- term storage in the genebank: 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 646 germplasm accessions (sorghum 546, chickpea 100) from the medium term storage of the genebank were evaluated for their seed health status using the standard blotter method. Only 19 off 646 accessions were free from seedborne pathogens (sorghum 10 and chickpea 9). We detected 21 fungi in sorghum and 11 in chickpea. Major fungi detected both in sorghum and chickpea were species of *Cladosporium*, *Alternaria*, and *Fusarium,* while species of *Phoma*, *Curvularia* and *Bipolaris* were specific to sorghum. These seedborne fungi affected seed viability up to 5% in sorghum and 4.2% in chickpea.

RP Thakur and HD Upadhyaya

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

A total of 2746 freshly harvested germplasm seed samples of different crops have been transferred to the cold rooms following standard protocols. This included, 1597 (sorghum 330, pearl millet 194, chickpea 217, pigeonpea 129, groundnut 727) accessions as active collection and 1452 (pearl millet 787, chickpea 418 and pigeonpea 247) accessions as base collection. With this addition the total number of accessions as base collection increased to 99,927 accessions representing 85.6% of total collection. Processing of sorghum and groundnut germplasm sets from the 2005-2006 postrainy season is in progress.

HD Upadhyaya

Activity A.4.2: Establish safety back up collections of staple crops

Milestone: A.4.2.1: Facilities identified for back up safety storage of germplasm collections in collaboration with partners and samples processed for safety backup (HDU/CLLG, Annual)

During this year, 1800 chickpea germplasm accessions were transferred as 'Black box' collection for safety back up at ICARDA genebank, Syria. Seed samples of 1677 accessions consisting groundnut (1478 accessions) and pigeonpea (199 accessions) were prepared following standard protocols.

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)

Gaps in germplasm characterization data was updated for 1233 accessions for days to 50% flowering and plant pigmentation in chickpea, for 261 to 6540 accessions for 37 traits in pigeonpea, and for 20 to 3509 accessions for 16 descriptors in groundnut.
Updated characterization databases for 1793 newly assembled accessions in chickpea, 296 accessions in pigeonpea, and 50 accessions in groundnut for the respective crop species descriptors.

HD Upadhyaya and CLL Gowda

Milestone A.5.1.2: Passport and characterization databases of sorghum and pearl millet germplasm updated (HDU, 2009)

Updated gaps in germplasm characterization databases for 10 to 3674 accessions in 24 traits in pearl millets, and for 47 to 614 accessions in 20 traits in sorghum
Updated characterization databases for 120 newly assembled accessions in sorghum, and 320 accessions in pearl millet for all crop species descriptors.
Updating of passport data of sorghum and germplasm databases is in progress.

HD Upadhyaya and CLL Gowda

Milestone A.5.1.3: Germplasm databases of staple crops updated to SINGER format (HDU, 2009)

Databases are being checked and updated for completeness of data 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)

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)

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)

Tested 1786 accessions of groundnut, and 168 accessions of sorghum during 2006 (pearl millet germination tests had been completed in 2003-04, no critical accessions found).

BIG Haussmann

Milestone: A.6.2.2: Critical accessions of groundnut, sorghum and millet regenerated in glasshouses at Sadore, Niger (BH, Annual)

No critical accessions found.

BIG Haussmann

Milestone: A.6.2.3: Germplasm accessions of groundnut, sorghum and pearl millet regenerated in the field at Sadore, Niger (BH, Annual)

A total of 1500 groundnut accessions multiplied in 2005 and processed in early 2006 for medium and long-term storage; sample size enhanced from 40 to 200 seeds per accession In sorghum 200 accessions were multiplied in 2005 and processed in early 2006 for medium and long-term storage. No further regeneration activities in 2006.

BIG Haussmann

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)

A total of 11,971 accessions have been conserved as safety duplicate at the Niamey genebank in 2006 (2006 groundnut, 5205 pearl millet and 4580 finger millet accessions).

BIG Haussmann

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)

A storage room for germplasm has been completed at Kiboko for processing germplasm for medium term storage. A seed drying room has also been completed and a dryer installed for drying seed for medium term storage. The medium term storage facility in Nairobi has been equipped with plastic trays (crates) for holding bottles containing germplasm accessions. This will facilitate easy arrangement and tracing of germplasm in the facility. Purchased a cooling system and installed at the Kiboko short-term storage facility and the following materials are currently stored. This was done with funds contributed by two special projects – The ABS and the SCOSA projects.

Regeneration of critical accessions for medium and long-term storage continues and new and additional germplasm identified for regeneration include the following:

- 529 African finger millet were conserved after first year of characterization
- 1081sorghum, 144 pigeonpea and 36 chickpea accessions rejuvenated in 2005 have been processed and stored
- Established 100 pigeonpea accessions as working collection
- 500 accessions of sorghum core collection evaluated
- 1060 sorghum accessions including those received form Zimbabwe and also photoperiod sensitive materials from Tanzania were rejuvenated and processed
- 382 pearl millet accessions were rejuvenated

MA Mgonja and SG Mwangi

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)

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 8516 samples of staple crops germplasm (sorghum-1806; pearl millet-1261; chickpea-2847; pigeonpea-1308; and groundnut-1294) for utilization to scientists in 23 countries in 111 consignments following standard protocols. Some of the special requests include sets of germplasm for collaborative evaluation with NARS in India and other countries (Table 1). The details are as follows:

Table 1. Distribution of germplasm sets for utilization during the year 2006.

Crop	Nature of set	No. Locations	Countries
Chickpea	Mini core	4	India (3) and Mexico (1)
Groundnut	Mini core	6	India (4), China (1) and Malawi (1)
Pearl millet	Core	6	India (5) and Niamey (1)
Pigeonpea	Mini core	7	India (6) and UAE (1)

Additionally, we provided 14206 samples of germplasm for internal utilization. The total includes, sorghum-3520; pearl millet-1647; chickpea-2915; pigeonpea-1986; and groundnut-4138.

RP Thakur, HD Upadhyaya and NBPGR

A total of 429 samples of 203 sorghum varieties were provided to nine ESA countries namely Tanzania, Kenya, Uganda, Ethiopia, South Africa, Botswana, Zimbabwe, Mozambique and Malawi and also to Mali. For pearl millet a total of 192 samples of 48 varieties were provided to Kenya, South Africa and Sudan.

MA Mgonja, E Manyasa and E Muange

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)

Export of germplasm of mandate crops: We processed and successfully exported 9077 seed samples (sorghum 2329, pearl millet 1462, chickpea 4042, pigeon pea 393 and groundnut 851) comprising of breeding lines and germplasm accessions to 40 countries under 141 phytosanitory certificates. Two hundred forty-one seed samples (sorghum 31, pearl millet 60, chickpea 117, pigeonpea 30, groundnut 2 and minor millet 1) were rejected due to poor germination and/or association of seedborne fungi (Exserohilum turcicum, Bipolaris setariae, Colletotrichum graminicola, Fusarium oxysporum f.sp. ciceri, Botryodiplodia theobromae, Rhizoctonia bataticola and R. solani), non-established FAO designated status of the samples, or bacterium-contaminated seed. During 2006, 85.8% more seed samples were exported than in 2005**.**

Bulk export of seed material: A bulk consignment of 435kg seed of four sweet sorghum varieties (SPV 422, ICSV 700, ICSV 93046 and ICSR 93046) was exported to Philippines and 7.5kg seed of Ber (*Ziziphus rotundifolia*) to Niger. The phytosanitory clearance for these consignments was obtained from the Directorate of Plant Protection, Quarantine and Storage (DPPQS), Hyderabad.

Import of germplasm of staple crops: We imported 2674 germplasm samples of: sorghum (483) from Niger, chickpea (1549) from Australia, Syria and USA, groundnut (634) from Japan, USA and Vietnam and Maize (8) from Italy. In addition, 324 maize accessions and 10 sorghum accessions imported by SM Sehgal Foundation from Egypt were planted in PEQIA for inspection and release by NBPGR.

Import of non-mandate crops' grain and plant samples: Through special import permit obtained from Directorate of Plant Protection, Quarantine and Storage (DPPQS), Faridabad we imported 800 dried and powdered samples of: maize stover (500) from Germany, wheat straw (100), wheat grains (100), Bersime

(*Trifolium alexandrium*) (50) and Lucerne (50) from Pakistan for ILRI-ICRISAT, and 140 soil samples from Pakistan for IWMI. All theses samples were required for various nutritional and chemical analyses.

Detection of *Peanut strip virus* (*PStV*) in groundnut: *PstV* was detected in several groundnut accessions grown in the greenhouse. The presence of *PstV* in some accessions was confirmed by ELISA and the infected seedlings were incinerated. Since the virus is aphid transmitted prophylactic sprays of Rogor® were given to avoid spread of the disease.

RP Thakur, HD Upadhyaya and NBPGR

A total of 28 samples of groundnut were distributed by the Niamey genebank in 2006.

BIG Haussmann

Crop researchers need to have access to diverse germplasm to develop improved broad genetic based cultivars; and to sustain biodiversity for current and future generations. A number of our NARS partners regularly request for materials in form of repatriated landraces germplasm, new breeding materials, finished and semi-finished products as well as nucleus seed of released varieties and hybrid parents for different uses. A total of 429 samples of 203 sorghum varieties were provided to 9 ESA countries namely Tanzania, Kenya, Uganda, Ethiopia, South Africa, Botswana, Zimbabwe, Mozambique and Malawi and also to Mali. For pearl millet a total of 192 samples of 48 varieties were provided to Kenya, South Africa and Sudan. The recipient organizations signed MTAs and these included NARIs, Universities, Seed Companies and NGO for research as well as for further multiplication. On the other hand we received from ICRISAT Patancheru a total of 441 sorghum and 11 pearl millet accessions from Zimbabwe

MA Mgonja, E Manyasa and E Muange

Output B: Germplasm of six small millets assembled and conserved, and an additional 10% of germplasm characterized/evaluated annually for desirable traits and documented for utilization

MTP Output Targets 2006

- *500 accessions of small millets regenerated at Patancheru*

- *Unrestricted access to and movement of small millet germplasm ensured*
- *(Annual activity)*

- *Safety copy of germplasm at Niamey genebank conserved and regenerated as appropriate (finger millet 4,580 accessions)*

- *Germplasm accessions regenerated for conservation and distribution (Annual activity)*

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)

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)

The foxtail millet germplasm database of Chinese Academy of Agricultural Sciences (CAAS), China was compared with ICRISAT database and identified foxtail millet – race: Moharia and subrace: Glabra (40 accessions), race: Maxima and subrace: Compacta (50 accessions), subrace: Spongiosa (50 accessions), race: Indica and subrace: Glabra (60 accessions) as unique for ICRISAT genebank.

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)

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)

Data of 20 finger millet accessions and four control cultivars evaluated in a replicated trial during 2005-2006 were analyzed. IEs 2340, 3194, 3790, 4974, and 6142 (116.7 – 188.3 cm) were significantly taller than the tallest control PR 2 and can be a source for feed and fodder. IEs 2498 and 4974 (56.7 – 61.7 mm) had wider inflorescence than the widest control RAU 8 ((55.0 mm). IEs 2498, 2683, and 2983 (10.7 – 11.3) have greater width of the longest finger than the best control PR 202 (10.00 mm). IEs 2498, 2578, 2887, 2903, and 4974 (11.1 – 13.4 g 1000 seed weight) had significantly greater seed size than the large seeded control RAU 8 (8.6 g). IEs 94, 2578, 3790, 3802, 4974, and 6236 (2.01 – 2.61 t ha^{-1}) were good for grain yield. To update characterization database 208 accessions were characterized.
C.L.L. Gowda and H.D. Upadhyaya

In a collaborative trail with the MPKV, Kolhapur, Maharashtra, India, 65 accessions of finger millet and five control cultivars were evaluated. IE 2957 (66 days) flowered earlier than all the five controls. 27 accessions (86-99 cm) were taller than the tallest control (85cm). Panicle exertion was significantly greater in IEs 2034, 2572, 3077, 3317,3945, 3952, 4734, and 6337 (15-88 cm) than all the five controls ((5-13 cm). IE 3475 (13) had significantly greater number of basal tillers than all the five controls (3-6). IEs 3045 and 4491 (10-11) had significantly greater inflorescence length than all the five controls (5-6 cm). IEs 2437, 2589, 3945, 3952, 5367, 6154, and 6421 (6-7 cm) had significantly greater inflorescence width than all the controls 9(4 cm). IE 3077 (5.03 t ha^{-1}) had greater grain yield than all the controls (2.64 – 4.82 t ha^{-1}).

1000 accessions of finger millet were evaluated and regenerated during 2006. Data recording is in progress.

CLLGowda, DD Kadam and HD Upadhyaya

Milestone B.2.2.2: Germplasm of foxtail millet, little millet, kodo millet, proso millet and barnyard millet characterized and regenerated (CLLG/HDU, 2009)

Data of 20 foxtail millet accessions and four control cultivars evaluated in a replicated trial during 2005-2006 were analyzed. Eleven accessions (38–45 days) flowered significantly earlier than the earliest control ISe 375 (56 days). ISe 1258 and ISe 1658 (38 days) were the earliest accessions. ISe 769 and ISe 1434 (159.3 – 161.3 cm) were significantly taller than the tallest control ISe 1541 (146.7 cm). ISe 1433 and ISe 1434 (3.0) had significantly greater number of basal tillers than all the four controls (1.0-2.0).). ISe 1433 and ISe 1434 (234.7 – 239.3 mm) had significantly greater inflorescence length than all the four controls (131.7 – 198.7 mm). ISe 1434 (2.06 t ha^{-1}) had significantly greater grain yields than all the four controls (0.81 – 1.53 t ha^{-1}).

One hundred and forty eight accessions of foxtail millet, three accessions each of barnyard and little millet, two accessions of proso millet, and ten accessions of kodo millet were characterized to update databases during 2005-2006. Four accessions of barnyard millet, one accession each of foxtail millet and kodo millet, and five accessions of little millet are being characterized for updating databases during 2006-2007. Data recording is in progress.

CLL Gowda and HD Upadhyaya

Of the 159 accessions and four control cultivars of foxtail millet evaluated in an augmented design trial, 21 accessions (25-40 days) flowered significantly earlier than the earliest control ISe 1541 (47 days). ISe 1161, ISe 1227, ISe 1234, ISe 1254, and ISe 1320 (25 – 33 days) were the five earliest flowering accessions. The 21 accessions (5-8) had significantly greater number of basal tillers than all the controls (1-2). ISe 796, ISe 1009, ISe 1026, ISe 1134, ISe 1408, and ISe 1892 (6-8) were the best tillering accessions. ISes 719, 827, 1151, 1161, 1163, 1227, 1286, 1312, 1320, 1547, 1563, 1593, and 1655 (200.3 – 274.7 mm) had significantly greater Panicle exertion than all the four controls (120.7 – 196.0 mm). ISe 785 (257.3 mm) had significantly greater inflorescence length than all the control cultivars (120.3 196.0 mm). ISe 1780 (40.4 mm) had significantly greater inflorescence length than all the control cultivars (18.1 – 30.7 mm) and ISe 1593 (13.2 g) had significantly greater panicle weight than all the control cultivars (7.4 – 9.9 g).

500 accessions were evaluated and regenerated during 2006. Data recording is in progress.

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 to for medium- and long-term conservation (HDU, Annual)

During the year, we regenerated 127 critical accessions of finger millet (15), foxtail millet (46), barnyard millet (42), little millet (2), proso millet (17), and kodo millet (5) for conservation and distribution. We also regenerated 20 accessions of six small millets in which seeds stocks are below critical levels under glasshouse conditions.   1500 accessions of two small millet crops (finger millet and foxtail millet) while grown essentially for evaluation were also used for replenishing stocks of the active collections.

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)

Milestone B.3.1.3: Small millets germplasm processed for safety back up (CLLG/HDU/BH, Annual)

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 2006 we distributed a total of 1125 samples of small millets germplasm (finger millet-1038; foxtail millet-25; proso millet-17; little millet-15; kodo millet-15; and barnyard millet-15) for utilization to scientists in three countries in 15 consignments. Some of the special requests include sets of germplasm for collaborative evaluation with NARS in India and other countries. The finger millet germplasm distribution includes 1000 accessions of composite set along with three controls for evaluation at Tamil Nadu Agricultural University, Coimbatore, India.

Additionally, we provided 127 samples of germplasm for internal utilization. The total includes, finger millet-15; foxtail millet-46; proso millet-17; little millet-2; kodo millet-5; and barnyard millet-42.

RP Thakur, HD Upadhyaya and NBPGR

Unrestricted access to and movement of staple crop germplasm ensured: Crop researchers need to have access to diverse germplasm to develop improved broad genetic based cultivars; and to sustain biodiversity for current and future generations. A number of our NARS partners regularly request for materials in the form of repatriated landraces germplasm, new breeding materials, and finished and semi-finished products as well as nucleus seed of released varieties and hybrid parents for different uses. A total of 553 samples of 369 finger millet accessions were provided to Tanzania and Malawi and Sudan. The recipient organizations signed MTAs and these included NARIs, Universities, Seed Companies and NGOs for research as well as for further multiplication. On the other hand we received from ICRISAT Patancheru, a total of 441 sorghum and 11 pearl millet accessions from Zimbabwe

MA Mgonja, E Manyasa and E Muange

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 17 small millets (foxtail millet 8 and finger millet 9) were exported to Botswana (7 samples) and Sudan (10 samples).

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)

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)

Upgrading storage modules: 8 new deep freezers received in 2006 and installed (total of 20 deep freezers now functioning at Niamey genebank).

BIG Haussmann

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)

Documented the characterization data of 1000 finger millet composite collection and 155 accessions of foxtail millet core collection for important morpho-agronomic characters. Additionally, data on grain characters for 224 accessions of little millet was documented.

HD Upadhyaya

Milestone B.6.1.2: Gaps in germplasm characterization data filled for small millets (HDU, 2008)

Gaps were updated in characterization databases for 1000 accessions in finger millet, 155 accessions in foxtail millet, and 224 accessions of little millet.

HD Upadhyaya

Milestone B.6.1.3: Germplasm databases of small millets updated to SINGER format (HDU/CLLG, 2009)

Databases of small millets are being checked and updated for completeness of data 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

MTP Output Targets 2006

- *Trait specific germplasm of five mandate crops available for utilization (annual activity)*
- *Chickpea composite set (3000 accessions) established for utilization*
- *Chickpea composite set (3000 accessions) genotyped with SSR markers in collaboration with ICARDA*
- *Germplasm reference collection for chickpea (300 accessions) established*
- *Sorghum composite set (3000 accessions) genotyped with SSR markers in collaboration with CIRAD and CAAS*
- *Minicore of pigeonpea germplasm established*

Output target C.1: Core and mini core subsets of germplasm established for utilization (2010)

Activity C.1.1: Establish core and mini core collections of staple crops and small millets

Milestone C.1.1.1: Mini core sub set of pigeonpea germplasm established (HDU/CLLG, 2006)

A mini core of pigeon pea consisting of 146 accessions was constituted, by evaluating a core collection of 1256 accessions. Validation of mini core by examination of data for various morphological and agronomic traits indicated that almost the entire genetic variation and a majority of co adapted gene complexes present in core subset are preserved in the mini core collection. Due to its greatly reduced size, the mini core subset will provide a more economical starting point for proper exploitation of pigeonpea genetic resources for crop improvement for food, feed, fuel, and other agricultural and medicinal purposes. A journal article on the development of finger millet mini core subset has been published Crop Science (46: 2127-2132).

HD Upadhyaya and CLL Gowda

Milestone C.1.1.2: Mini core subset of sorghum established (HDU/CLLG, 2008)

Data analysis and assessment of diversity is in progress for establishment of sorghum mini core subset.

HD Upadhyaya and CLL Gowda

Milestone C.1.1.3: Mini core subset of finger millet established (HDU/CLLG, 2009)

Milestone C.1.1.4: Core subset of foxtail millet established (CLLG/HDU, 2010)

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)

Groundnut: Composite collection comprising of 911 accessions from ICRISAT and 192 from EMBRAPA was developed using phenotypic characterization & evaluation data. The composite set included 184 accessions each of groundnut mini core collection (Upadhyaya et al, 2002) and mini core comparator. Among these 50 accessions are chilling tolerant at germination (Upadhyaya et al., 2001) and 18 accessions are drought tolerant (Upadhyaya, 2005a). We included 50 accessions from groundnut mini core for Asia region and 60 accessions having traits of economic importance from groundnut core collection for Asia region (Upadhyaya et al., 2005b). We included 36 elite/released varieties (27 from breeding and 9 from germplasm), and lines resistant to biotic stresses (5 leaf miner, 1 aphid, 10 jassid, 4 thrips, 7 termite, 2 PMV, and 12 rosette, 27 *A. flavus*/aflatoxin, 9 bacterial wilt, 7 bud necrosis, 7 early leaf spot, 14 late leaf spot, and 5 LLS & rust resistant interspecific derivates, 15 rust, 9 stem and pod rot, 41 multiple resistant). (Table 1). We also included 41 drought tolerant, 6 fresh seed dormancy lines, 4 high nitrogen fixing lines, 5 non-nodulating, 25 early maturing, 16 large seeded, 10 high shelling percentage, 9 high oil containing, 9 high protein containing, beside 26 accessions for morphological variants. To represent wild species of *Arachis* species, 52 accessions of 14 species were included (Table 2).

Table 2. Composite collection of groundnut

Character	Number of accessions	Character	Number of accessions
Mini core (50 chilling tolerant, 18 high SPAD)	184	Rust resistant	15
Mini core comparator	184	Stem & pod rot resistant	9
Asia mini core	50	Multiple resistant	41
Best accessions from Asia core	60	Drought tolerant	41
Released/elite cultivar	36	Fresh seed dormancy	6
Leaf miner	5	High biological nitrogen fixation	4
Aphid resistant	1	Non-nodulating	5
Jassid resistant	10	Early maturing	25

Character	Number of accessions	Character	Number of accessions
Thrip resistant	4	Large seeded	16
Termite tolerant	7	High Shelling turn over	10
Peanut mottle virus	2	High oil content	9
Rosette virus resistant	12	High protein content	9
A. flavus resistant	27	High SPAD	1
Bacteria wilt resistant	9	Interspecific derivates	5
Bud necrosis resistant	7	Morphological variance	26
Early leaf spot resistant	7	Used by Morag Ferguson	18
Late leaf spot resistant	14	14 wild *Arachis* species (2 *batizocoi*, 7 *cardenasii*, 1 *chiquitana*, 1 *diogoi* (*chacoensis*), 19 *duranensis*, 2 *hoehnei*, 1 *ipaensis*, 2 *kempff-mercadoi*, 3 *monticola*, 1 *paraguariensis*, 1 *stenophylla*, 9 *stenosperma*, 2 *villosa*, and 1 *villosulicarpa*)	52 (1 each resistant to thrips and rust, and ELS, 2 each resistant to LLS and root rots, 3 for high SPAD, and 9 multiple resistant accessions)

HD Upadhyaya, R Bhattacharjee, CLL Gowda, RK Varshney and DA Hoisington.

Pigeonpea: Pigeonpea composite collection consisting of 1000 accessions was constituted based on phenotypic, taxonomic and characterization/evaluation data The composite collection includes accessions – minicore collection (146), minicore comparator (146), from core collection (236), superior morpho-agronomic traits (301), resistant to biotic stresses (74), resistant to abiotic stresses (14), elite/released cultivars (20), and 65 accessions of 7 wild species (Table 3).

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	*Trait specific selections*	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

HD Upadhyaya, R Bhattacharjee, CLL Gowda, RK Varshney, DA Hoisington and KB Saxena.

Pearl millet: We constituted a pearl millet composite collection of 1000 accessions and grown for characterization and regeneration during the rainy season (Table 4).

Table 4. 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	
P. mollissimum	6
P. orientale	1
P. pedicellatum	15
P. polystachion	15
P. ramosum	2
P. schweinfurthii	1
P. violaceum	20
Contribution from crop improvement	47
Total	1000

HD Upadhyaya, CT Hash, S Senthilval, RK Varshney,
DA Hoisington, KN Rai and RP Thakur.

Milestone C.2.1.2: Germplasm composite sets for finger millet (1000 accessions) and foxtail millet (500 accessions) established (HDU/CTH/DH/CLLG/RKV/SC, 2008)

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, BJF, 2006)

Composite collection of chickpea was developed based on available phenotypic, characterization, evaluation, geographic origin, and taxonomic data. It includes 2271 cultivated and three wild genotypes from ICRISAT and 726 cultivated and 13 wild accessions from ICARDA. This composite collection was genotyped using high throughput assay (ICRISAT: ABI3700 and ICARDA: ABI3100) and 50 SSR markers. ICRISAT generated data on 35 SSR loci and ICARDA on 15 SSR loci on 3000 accessions (Table 5).

Identification of Markers: Identified 50 polymorphic SSRs for genotyping the global composite collection from preliminary screening of 288 diverse chickpea germplasm accessions with 200 SSRs in 2004. Three di-and tri-nucleoid repeat motifs markers were of 174-241 (bp) allele size at annealing temperature of 60-65^{o}C (Huttel et al., 1999), 42 di-and tri-nucleoid repeat motifs markers were of 132-436 (bp) allele size at annealing temperature of 55- 65^{o}C (Winter et al., 1999), and 5 di- nucleoid repeat motifs markers were of 195-306 (bp) allele size at annealing temperature of 60-65^{o}C (Niroj et al., 2003).

Data Generated: ICRISAT and ICARDA were involved in genotyping of the composite collection using high throughput assay and 50 SSR markers. ICRISAT generated 35 SSR loci data and provided sufficient and good quality DNA for the 3000 accessions to ICARDA. ICARDA generated 15 SSR loci data.

All allelic data for 50 SSR primers on 3000 accessions resulted in less than 5% missing data (i.e., marker x genotype). The dataset was then analyzed using the allele-binning algorithm of Idury and Cardon (1997) called “Allelobin”. The quality index of the markers was calculated based on missing data recorded for each of the markers and also to see if there was any allelic drift for these markers. Except for TA21, TA22, TA28, and TA58 (data not shown), all markers produced an allele size expected on the basis of SSR repeat motif.

Data templates consisting of 105000 (3000 x 35) data points generated at ICRISAT has been delivered to GCP repository. Data templates consisting of 45000 data points (3000 x 15) generated at ICARDA are currently being checked for completeness will be delivered to repository soon after verification by ICARDA

Table 5. Number of missing data, allele number and variation in allele size (bp) as detected in 3000 accessions genotyped for 50 SSR loci.

Locus	Missing data	No. of Alleles detected	Allele size range (bp)
TA206	224(7.5)	33	350-449
CaSTMS15	292(9.7)	30	209-368
CaSTMS2	332(11.1)	30	209-326
CaSTMS21	176(5.9)	21	150-210
NCPGR12	352(11.7)	28	206-272
NCPGR19	200(6.7)	29	288-464
NCPGR4	124(4.1)	16	149-203
NCPGR6	202(6.7)	24	213-361
NCPGR7	298(9.9)	15	201-243
TA113	258(8.6)	20	145-238
TA116	296(9.9)	34	159-276
TA117	714(23.8)	37	173-323
TA118	212(7.1)	43	116-263
TA130	360(12)	23	185-254
TA135	178(5.9)	21	125-221
TA14	132(4.4)	41	210-354
TA142	258(8.6)	23	113-197
TA200	132(4.4)	39	250-379
TA21	392(13.1)	42	275-422
TA22	344(11.5)	50	131-344
TA27	284(9.5)	32	192-306
TA28	252(8.4)	58	231-438
TA46	586(19.5)	24	126-195
TA64	182(6.1)	36	173-284
TA71	228(7.6)	41	139-277
TA72	312(10.4)	50	159-375
TA76s	458(15.3)	34	149-314
TAA58	190(6.3)	45	205-349
TaaSH	106(3.5)	40	301-496
TR2	206(6.9)	53	161-326
TR29	208(6.9)	34	127-259
TR31	150(5)	16	165-234
TR43	256(8.5)	55	249-474
TR7	242(8.1)	27	146-248
TS84	210(7)	16	197-266
Ta2	180(6)	68	93-251
Ta80	156(5.2)	35	148-275
Ta203	240(8)	56	160-294
Ta5	128(4.3)	43	155-293
Ta96	224(7.5)	48	161-324
Tr1	216(7.2)	62	133-324
Ta3	236(7.9)	30	205-305
Ta8	50(1.7)	34	174-280

Locus	Missing data	No. of Alleles detected	Allele size range (bp)
Ta144	156(5.2)	56	179-287
Ta42	104(3.5)	46	101-251
Ta176	134(4.5)	65	146-365
Ts45	142(4.7)	27	134-274
Ta11	256(8.5)	30	158-296
Ta78	88(2.9)	39	95-262
Ta194	54(1.8)	30	87-291

ICRISAT-HD Upadhyaya, SL Dwivedi, CLL Gowda, PM Gaur, RK Varshney, DA Hoisington and S Chandra; ICARDA- SM Udupa, M. Baum and BJ Furman

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/JFR/MD/LG/RR; CAAS-YL/TW/PL, 2006)

A total of 3393 sorghum lines, including 10 duplicates, have been genotyped at 43 SSR loci (marker data provided by CIRAD and ICRISAT; the SSR data provided by CAAS for an additional 5 SSR primer pairs has not been included in the final data set). Some 6% of the 145,889 potential data points were missing, so several SSRs and lines were removed from the analysis due to unacceptably high frequency of missing data, leaving 3365 sorghum lines and 39 SSR loci. This represents 87.5% of our original target of 3000 sorghum lines genotyped at 50 SSR loci. The composite set of sorghum lines for which adequate marker data are available for diversity analysis is comprised of 2.0% wild accessions, 8.6% breeding lines and released cultivars, and 98.4% landrace accessions representing all five major races of sorghum and their 10 intermediates, as well as materials originating from 13 sub-continents.

ICRISAT - CT Hash, HD Upadhyaya, Punna Ramu,and DA Hoisington; CIRAD – C Billot, J-F Rami, L Gardes, R Rivalian,and M Deu; CAAS – Y Li, T Wang and P Lu.

Milestone C.3.1.3: Reference collection of chickpea (300 accessions) established (HDU/ DH/RKV/CLLG/ PMG, 2006)

All allelic data for 50 SSR primers on 3000 accessions resulted in less than 5% missing data (i.e., marker x genotype). The accessions with maximum missing values were removed and based on analysis on 2915 accessions, we have selected a reference set consisting of 300 accessions. This reference set consists of 211 accessions of mini core (Upadhyaya and Ortiz, 2001), which has been phenotyped for several traits including drought tolerance traits, and another 89 accessions. The reference set captured 78% (1403 alleles) of the 1791 alleles detected in the 2915 accessions of composite collection. Biologically, the reference set consists of 267 landraces, 13 breeding lines/cultivars, 7 wild *Cicer* accessions, and 13 accessions with an unknown biological status. Geographically it consists of accessions from Asia (198), Africa (21), Europe (3), Mediterranean (56), Americas (10), Russian Federation (6), and 6 accessions whose geographical origin is not known. The reference set has 195 desi, 88 kabuli, and 10 intermediate type (pea-shaped), and 7 wild *Cicer* accessions. The reference set is diverse and can be used for extensive phenotyping for traits of interest and genotyping for association studies and eventually for efficient allele mining.

HD Upadhyaya, DA Hoisington, RK Varshney, CLL Gowda and PM Gaur

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)

Sorghum diversity in Mali assessed by microsatellite markers: We collected wild, weedy (60 types) and cultivated Sorghums (340 varieties) in 60 villages from all Sorghum agro-ecological regions in Mali (except the "décrûe" Sorghums from Gao region). Sorghum seeds were germinated in a greenhouse. DNA was isolated from fresh leaves collected on 1-3 week old seedling per variety following a modified CTAB protocol at the University of Bamako (Mali). Fifteen SSR markers were chosen among those selected for their reliability and scoring accuracy among laboratories, their level of polymorphism and genome coverage, for the Challenge Program Generation. The M13-tails added to forward primers for each SSR were labeled with IRD700 or IRD800 Xuorochromes. Plants were genotyped at the Montpellier Languedoc-Roussillon Genopole (France) platform using Li-Cor automated sequencers. Saga GT v. 2.2 (Li-Cor) was used to determine allele sizes. First analyses showed a strong genetic structuration between Sorghum botanical races in Mali with wild/weedy Sorghums genetically closer to the guinea margaritiferum cluster.

F Sagnard in collaboration with CIRAD and University of Bamako, Mali

Milestone C.3.1.5: Diversity of wild and cultivated Pearl Millet in Niger published (FS, JN, BG, IRD, CIRAD, NARS, 2006)

Diversity analysis of Pearl Millet to identify priorities for conservation programs: In Niger, pearl millet covers more than 65% of the total cultivated area. Analyzing pearl millet genetic diversity, its origin and its dynamics is important for *in situ* and ex situ germplasm conservation and to increase knowledge useful for breeding programs. Using 25 microsatellite markers, the genetic diversity of 46 wild and 421 cultivated accessions showed a significantly lower number of alleles and lower gene diversity in cultivated pearl millet accessions than in wild accessions. A strong differentiation between the cultivated and wild groups in Niger was observed. Wild accessions in the central region of Niger showed introgressions of cultivated alleles. Accessions of cultivated pearl millet showed introgressions of wild alleles in the western, central, and eastern parts of Niger. A journal article has been published in the Theoretical and Applied Genetics (114: 49–58).

F Signard, B Gerard and J Ndejeunga in collaboration
with CIRAD and University of Bamako, Mali

Milestone C.3.1.6: Diversity of sorghum composite collection analyzed and reference set (300 accessions) established (ICRISAT--CTH/HDU/SS/RKV/DH/CLLG/SC/JB; CIRAD--CB/JFR/MD/LG/RR; CAAS-YL/TW/PL, 2007)

Diversity analysis of the sorghum composite collection was initiated in 2006 using a subset of 3365 sorghum lines genotyped at 39 single-copy SSR loci. The marker data clearly demonstrate the tremendous range of genetic diversity available in this sorghum composite collection. We detected an average of 19 alleles per SSR locus and the vast majority of the alleles detected are rare (>75% of alleles having frequencies <5%, and >50% of alleles detected having frequencies <1%).

The data set was analyzed using a factorial analysis of the simple matching dissimilarity index implemented in the Darwin diversity analysis software package. The overall picture emerging from this analysis is one of complex genetic structure within sorghum germplasm—as expected from previous studies of sorghum genetic diversity based on passport information, morphological characters, and RFLP marker data. Several distinctly different groups of wild accessions were detected. Among landrace accessions, race bicolor lacked structure and was found scattered across the first two axes of the factorial analysis. Race kafir accessions formed a single group, as expected from their origin from a relatively compact region in southern Africa. Race durra accessions formed four groups, each associated with a specific geographic region (eastern Africa, southern Africa, the Indian sub-continent, and eastern Asia), and these were congruent with four groups of caudatum accessions (Fig 1). This finding is in agreement with earlier studies that have found greater similarities in molecular marker genotype between landrace accessions of difference races but originating from a common region than between landrace accessions of a common race originating from different regions. The guinea race accessions also exhibited considerable structure, with separate groups of materials originating from eastern and southern Africa, western and central Africa, and the Indian subcontinent, as well as a clearly defined subgroup comprised of the margaritiferums that may represent an independent domestication event. Intermediate-race landrace accessions also formed distinct clusters (by hybrid race and geographic region). We are now attempting to use this information to choose a representative “core” or “reference” subset of 300 to 500 accessions for more detailed study.

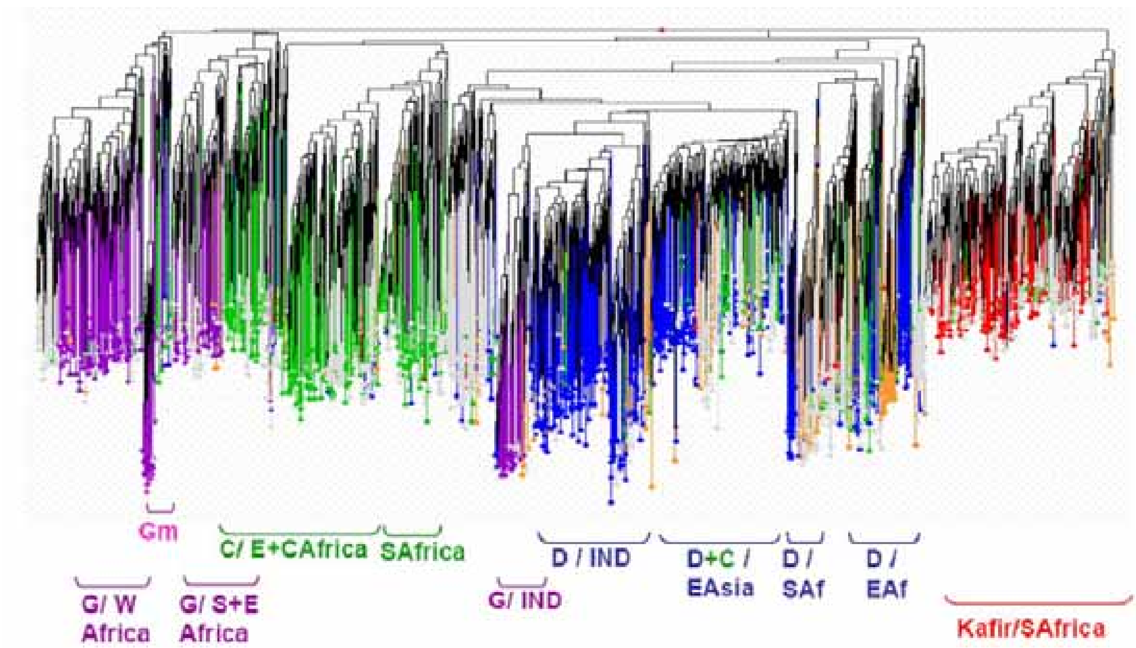
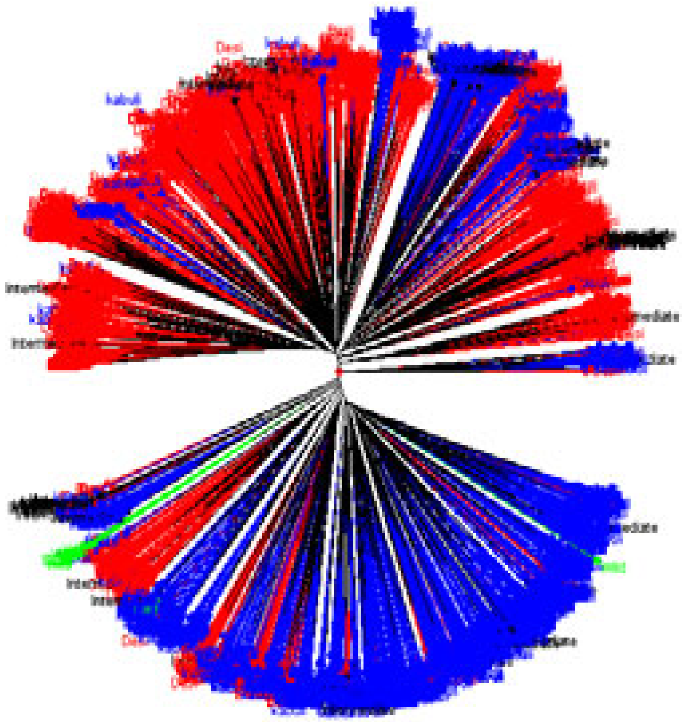


Fig 1. Relationships among 3008 sorghum landrace accessions in the Generation Challenge Program composite germplasm collection for sorghum, based on allelic variation at 39 SSR loci distributed across all 10 sorghum linage groups. In this figure landraces representing the five major sorghum races are colored: race bicolor accessions are orange, race kafir are red, race durra (D) are blue, race caudatum (C) are green, and race guinea (G) are purple (including the margaritiferum group, Gm). Geographic regions from which the different groups of accessions originated are: W Africa = Western Africa; S Africa = Southern Africa; E Africa = Eastern Africa; C Africa = Central Africa; IND = Indian subcontinent; and, E Asia = Eastern Asia (Figure courtesy of Claire Billot).

ICRISAT - CT Hash, HD Upadhyaya, Punna Ramu and DA Hoisington;
CIRAD – C Billot, J-F Rami, L Gardes, R Rivalian and M Deu;
CAAS – Y Li, T Wang and P Lu.

Milestone C.3.1.7: Genetic diversity and population structure of chickpea and sorghum assessed (HDU/CTH/RKV/PR/CLLG/SC/DH/PMG/MB/SMU/CB/JB/SC, 2007)

Chickpea:
The composite collection was genotyped using high throughput assay (ICRISAT: ABI3700 and ICARDA: ABI3100) and 50 SSR markers. ICRISAT generated data on 35 SSR loci and ICARDA on 15 SSR loci on 3000 accessions. Except for TA21, TA22, TA28, and TA58, all markers produced an allele size expected on the basis of SSR repeat motif). Preliminary data analysis detected 1829 alleles, ranging from 15 to 68 alleles with an average of 36.6 alleles per SSR locus. Mean PIC (Polymorphism Information Content) value of 0.858 (ranging from 0.471 to 0.974) and gene diversity 0.873 (ranging 0.536 – 0.975) were observed in the entire composite collection (Table 6). Kabuli types were more genetically diverse than the other three types. Gene diversity ranged from 0.253 to 0.965 in kabuli types, 0.419 to 0.974 in desi, 0.479 to 0.955 in pea-shaped, and 0.560 to 0.928 in wild types. Accessions from the West Asia region revealed high gene diversity (0.871) while those from Oceania revealed lowest gene diversity (0.504) (Table 5). Detected 1539 rare and 290 common alleles at 5% and 1137 rare and 692 common alleles at 1% in the entire composite collection. There were 252 alleles that were detected in all the four biological groups (desi, kabuli, pea-shaped, and wild relatives). Accessions from the Mediterranean region had the largest number of region-specific alleles (137) and 69 alleles were common across all the seven geographical regions. Principal coordinate analysis delineated the accessions in two clusters (Fig 2). The desi and kabuli chickpeas each formed two distinct clusters; however, a number of desi chickpeas also grouped into kabuli cluster indicating progressive evolution of kabuli traits from the desi chickpeas.



Desi (1668); Kabuli (1167); Intermediate (70); Wild (10)

Fig. 2. Genetic structure of the global composite collection (50 SSR loci and 2915 accessions) of chickpea as revealed by the Principal Coordinate Analysis (PCoA) using DARwin 5.0 Structure program.

Table 6. Range and average PIC values and gene diversity in the global composite collection of chickpea.

Category	**No. of accessions**	**PIC**		**Gene Diversity**	
		Average	**Range**	**Average**	**Range**
Composite collection	3000	0.858	0.471-0.974	0.873	0.536 - 0.975
Composite collection	2915	0.858	0.468 –0.974	0.872	0.534 - 0.975
Reference sample	300 (211+89)	0.872	0.488 –0.964	0.884	0.540 - 0.965
Biological classification					
Desi chickpea	1712	0.836	0.382-0.973	0.851	0.419 - 0.974
Kabuli chickpea	1197	0.835	0.243-0.963	0.849	0.253 - 0.965
Pea-shaped chickpea	71	0.823	0.443-0.953	0.842	0.479 - 0.955
Wild species	20	0.834	0.499-0.923	0.850	0.560 - 0.928
Geographical classification					
Africa	153	0.791	0.297-0.946	0.806	0.308 - 0.949
North and Central America	95	0.815	0.431-0.944	0.834	0.478 - 0.946
South America	50	0.757	0.113-0.938	0.779	0.117 - 0.941
South and southeast Asia	1163	0.81	0.322-0.968	0.826	0.348 - 0.969
West Asia	740	0.858	0.451-0.967	0.871	0.478 - 0.968
Russian Federation	45	0.781	0.338-0.937	0.800	0.369 - 0.940
Mediterranean	650	0.824	0.260-0.964	0.839	0.272 - 0.839
Europe	66	0.794	0.167-0.932	0.809	0.173 - 0.936
Oceania	3	0.428	0.000-0.810	0.504	0.000 - 0.833
Unknown	35	0.837	0.469-0.935	0.854	0.545 - 0.939

ICRISAT- HD Upadhyaya, SL Dwivedi, CLL Gowda, RK Varshney and DA Hoisington; ICARDA- SM Udupa, M Baum,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)

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)

Milestone C.3.1.10: Comparative phylogeography of wild, weedy and cultivated Sorghums in Mali published (FS, PST, NARS + CIRAD, 2008)

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)

Milestone C.3.1.12: Diversity assessment of sorghum and chickpea published (HDU/CTH/RKV/CLLG/SS/DH/SC/JB, 2009)

A journal article "Development of a composite collection for mining germplasm possessing allelic variation for beneficial traits in chickpea' published in Plant Genet. Resources 4: 13-19.

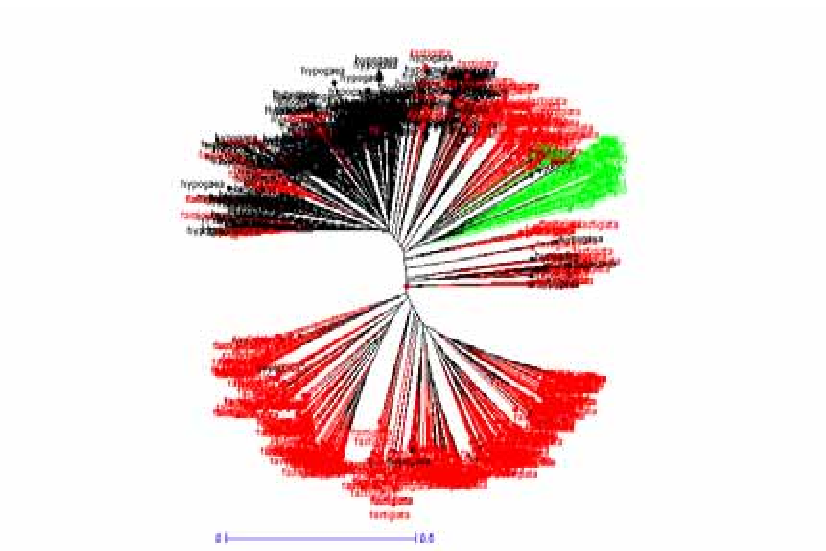
A poster "Genotypic and phenotypic variation in the global collection of chickpea (*Cicer aritienum* L.)" presented at the Third International Conference on Legume Genomics and Genetics, 9-13 April 2006, Brisbane, Queensland, Australia.

HD Upadhyaya, SL Dwivedi, CLL Gowda, RK Varshney,
DA Hoisington,and S Chandra

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)

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/JB, 2008)

A preliminary analysis of data on 916 groundnut accessions and 21 SSR markers was carried out using DARwin 5.0 Structure program to determine the population structure of the composite collection. The software removes all those accessions/markers that have high missing values and finally 900 accessions were considered for principal coordinate analysis considering the taxonomical classification of *Arachis*, i.e. at the level of two subspecies and six botanical varieties. The analysis detected a total of 506 alleles, ranging from 6 (7H6) to 47 (5D5) with a mean of 24.1 alleles per locus and mean PIC value of 0.797 (ranging from 0.483 to 0.923)

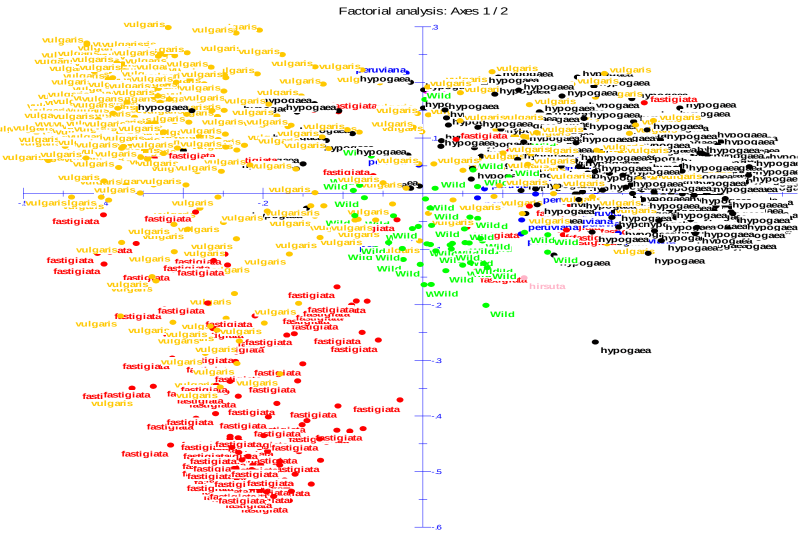


fastigiata: Red; *hypogaea:* Black; Wild: Light Green

Fig. 3. Tree diagram of 900 accessions with 21 SSR markers at subspecies level.

Principal coordinate analysis (PCoA) using DARwin 5.0 on subspecies revealed that both *hypogaea* and *fastigiata* formed distinct clusters however, a number of *fastigiata* accessions also grouped with *hypogaea* types

(Fig. 3), which maybe attributed to the geographic origin of these accessions. This is also confirmed when PCoA was performed considering botanical varieties (Fig. 3). The wild accessions formed a different cluster in both the cases and grouped with *hypogaea* types, indicating a close relation between them (Fig. 3 & 4).



fastigiata: Red; *hypogaea:* Black; *peruviana:* Blue; *vulgaris:* Orange; *hirsuta:* Pink; *aequatoriana:* Magenta; Wild: Light green

Fig. 4. Factorial analysis at the level of botanical varieties.

Further analysis of data is in progress to fully understand the genetic structure of groundnut composite collection. The results from genotypic data will be used to select the reference set of 300 accessions for future use.

To ascertain the quality and position of the SSR markers, these will be checked on 15-20 plants in each of three F_2 populations, whose parents have been included in the composite collection. Only those SSR markers that showed polymorphism on the parents will be checked on the F_2 population. Three crosses involving five parents have been selected for this purpose and 14 out of 21 markers have been found to be polymorphic between the parental combinations. The F_2 populations are being genotyped presently and the results will confirm the location/position of these SSR markers and would ensure appropriate peak calling. Data generated from the fingerprinting will be then subjected to statistical analysis using different computational tools.

HD Upadhyaya, R Bhattacharjee, CLL Gowda,
RK Varshney 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)

At ICRISAT, genotyping of 1000 accessions (composite collection) was carried out. DNA was extracted from 12 plants per accession and a series of artificial pools having different proportions of two genotypes showing polymorphism for a given SSR marker were developed and screened with the corresponding polymorphic SSR marker. The coefficients of correlations were analyzed between different proportion of alleles recorded (corresponding to 12 plants per accession) and proportion of genomic DNA used for the corresponding accession. As a result, 20 SSR markers with highly significant correlations (r^2> 0.9) were identified.

The selected 20 polymorphic SSR markers were optimized for PCR reactions following Taguchi method (Taguchi, 1986) as described in Cobb and Clarkson (1994). A fluorescent-based multiplex genotyping system was then used to generate different multiplexes, which 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 v 3.7 software. The allelic data was analyzed following allele binning algorithm, written in a C program at ICRISAT called as “Allelobin”, based on the least squares algorithm of Idury and Cardon (1997). Less than 5% missing data (i.e. marker x genotype) was recorded in the dataset and all the markers produced allele size that was expected on the basis of repeat motif of each of the SSR markers. Preliminary analysis has been completed on 17 out of 20 markers and 3 markers showed poor quality index (Table 6), which may be due to high missing vales recorded for these markers. Preliminary analysis detected a total of 184 alleles, ranging from 2 (PKS18) to 24 (CCB8) with a mean of 10.8 alleles per locus and mean PIC value of 0.31 (ranging from 0.02 to 0.0.59) (Table 7).

Table 7. SSR primers used in the study with information on their repeat units, quality index, number of alleles and PIC values.

Primer	Repeat Unit	Quality Index	No. of Accessions Genotyped	No. of Alleles	PIC Values
CCB1	(CA)10	0.26	1000	20	0.46
CCB9	(CT)22	0.46	951	18	0.53
PGM3	(GAA)5G(GAA)5	0.42	976	11	0.50
PGM101	(AC)7	0.14	984	8	0.43
CCB7	(CT)16	0.24	1000	17	0.47
PGM106	(AAG)13	0.31	1000	11	0.33
PGM109	(CTT)8	0.18	1000	5	0.44
CCB8	(CT)30	0.27	961	24	0.47
PKS21	(CT)6TT(CT)2	0.23	997	8	0.13
PGM5	(GAA)6	0.23	948	8	0.13
PGM10	(AGA)5	0.22	986	7	0.09
PGM16	(TC)8	0.26	962	7	0.17
PGM82	(AC)6AAG(CTAA)3	0.30	995	7	0.32
PKS18	(GGT)4	0.11	999	2	0.02
PKS25	(TTAT)4	0.40	967	10	0.50
PKS26	(TTA)4	0.17	931	7	0.07
CCB10	(CA)15	0.32	898	14	0.59

Principal co-ordinate analysis on 1000 accessions and 20 SSR markers was carried out using DARwin 5.0 Structure program to determine the population structure of the composite collection. The software removes all those accessions/markers that have high missing values and finally 970 accessions were considered for the analysis. Principal co-ordinate analysis grouped the accessions into two distinct clusters separating the cultivated accessions from the wild one's (Fig.5).

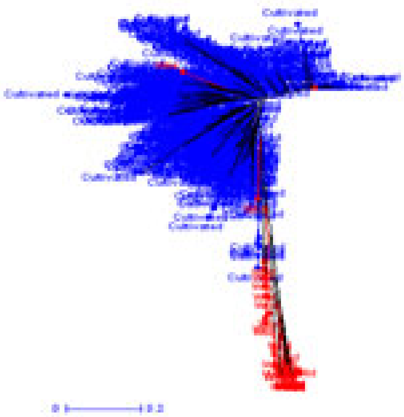


Fig. 5. Factorial analysis of 970 accessions with 17 SSR markers.

HD Upadhyaya, R Bhattacharjee, RK Varshney, DA Hoisington, CLL Gowda, and S Chandra

Milestone C.3.1.16: Data sets for groundnut and pigeonpea composite set made available globally via Internet (JB/HDU/RKV/DH/RB/CLLG/SC/KBS, 2010)

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)

Milestone C.3.1.18: Diversity and population structure of pearl millet composite collection analysed and reference set (300 accessions) established (HDU/CTH/ RKV/SS/DH/CLLG/SC/JB, 2010)

Pearl Millet: A set of 1000 accessions of pearl millet composite collection were planted in the field. DNA was extracted at 15th day from leaf tissues of 15 plants by using high – through put method and quality checked by using agarose gel electrophoresis. Quantification of DNA concentration has been done with fluorescence detector and diluted to 5 ng/ul as working concentration in ABI 3700. Twenty polymorphic SSR were selected for genotyping. PCR conditions optimized. Finger printing is in progress.

HD Upadhyaya, CT Hash, RK Varshney, S Senthelvel,
DA Hoisington, CLL Gowda, S.Chandra and B Jayashree

Milestone C.3.1.19: Diversity assessment of pearl millet published (HDU/CTH/SS/RKV/DH/SC/JB, 2010)

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)

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)

Activity C.3.3: Phenotypic and genotypic diversity assessment of sorghum germplasm in eastern and southern Africa

Milestone C.3.3.1: Phenotyping and genotyping of germplasm held by NARS (2006)

This study aims at characterizing and assessing diversity at the phenotypic and genotypic levels in sorghum germplasm currently used in NARS breeding programs in east and central Africa. The germplasm includes resources within national gene banks, international nurseries and important breeder germplasm. We have adopted a standardized approach to documentation, phenotyping and also in molecular characterization of the germplasm using 24 SSRs as part of the GCP set of high quality microsatellite markers that are being used for the survey of global composite set of sorghum germplasm. A project planning meeting was held in April 2006 in Nairobi, followed by a phenotyping workshop. Project partners agreed to work on a regional composite of 1720 accessions representing landraces, farmer varieties and breeders' lines. Seed multiplication and phenotyping of 1260 Sorghum accessions has started in Eritrea, Kenya, Uganda, Tanzania and Sudan. 27 consensus descriptors representing all the sorghum developmental stages are being used for morphological characterization. These are partially derived from the IPGRI descriptor lists for Sorghum. Characterization data is being generated and documented in the Access Database developed during the phenotyping workshop. Genotyping activities have been initiated, starting with the extraction, quantification and quality checks of DNA from 196 sorghum samples from Tanzania. The DNA will be used both for genotyping and repository as part of the GCP Sorghum global collection. Initial genotyping has started with the screening of 196 accessions using 6 polymorphic SSR markers. All the 24 SSR markers that will be used for genotyping have been optimized and screened for polymorphism. A database with an initial entry of 1260 germplasm accessions that are being phenotyped and genotyped by the participating NARS has been developed. The information on the accessions mainly comprises passport data and will be used to identify duplicates through the unique identifiers. Two PhD students have been registered at the University of Wad Medani and University of Free State, South Africa to phenotype and genotype 400 samples from Sudan. 4 MSc students have been registered in national universities in Ethiopia, Kenya, Uganda and Tanzania to advance the phenotyping and genotyping activities.

D Kiambi, DA Hoisington, CT Hash and S de Villiers

Milestone C.3.3.2: Phenotypic characterization of sorghum germplasm held by ESA NARS completed (DK, 2007)

Knowledge of the extent, nature and structure of genetic diversity in crop germplasm accessions is important for defining strategies for conservation and utilization. This project aims at characterizing and assessing diversity at the phenotypic and genotypic levels in sorghum germplasm currently used in NARS breeding programs in east and central Africa. The germplasm includes resources within national gene banks, international nurseries and important breeder germplasm. The project has adopted a standardized approach to documentation, phenotyping and also in molecular characterization of the germplasm using 24 SSRs as part of the GCP set of high quality microsatellite markers that are being used for the survey of global composite set of sorghum germplasm. A project planning meeting was held in April 2006 in Nairobi, followed by a phenotyping workshop. Project partners agreed to work on a regional composite of 1720 accessions representing landraces, farmer varieties and breeders' lines. Seed multiplication and phenotyping of 1260 Sorghum accessions has started in Eritrea, Kenya, Uganda, Tanzania and Sudan. 27 consensus descriptors representing all the sorghum developmental stages are being used for morphological characterization. These are partially derived from the IPGRI descriptor lists for Sorghum. Characterization data is being generated and documented in the Access Database developed during the phenotyping workshop. Genotyping activities have been initiated, starting with the extraction, quantification and quality checks of DNA from 196 sorghum samples from Tanzania. The DNA will be used both for genotyping and repository as part of the GCP Sorghum global collection. Initial genotyping has started with the screening of 196 accessions using 6 polymorphic SSR markers. All the 24 SSR markers that will be used for genotyping have been optimized and screened for polymorphism. A database with an initial entry of 1260 germplasm accessions that are being phenotyped and genotyped by the participating NARS has been developed. The information on the accessions mainly comprises passport data and will be used to identify duplicates through the unique identifiers. Two PhD students have been registered at the University of Wad Medani and University of Free State, South Africa to phenotype and genotype 400 samples from Sudan. 4 MSc students have been registered in national universities in Ethiopia, Kenya, Uganda and Tanzania to advance the phenotyping and genotyping activities.

D Kiambi, DA Hoisington, CT Hash and S de Villiers

Milestone C.3.3.3: Molecular characterization of germplasm held by ESA NARS completed (DK, 2007)

Milestone C.3.3.4: Phenotypic and molecular data for sorghum standardized and analyzed (DK, 2008)

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)

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)

Chickpea: 211 accessions of chickpea mini core collection with five control cultivars (Annigeri, ICCV 2, ICCV 10, L 550, KAK 2, G 130) were evaluated in augmented designed trials at Patancheru, Palampur, Chandigarh, and Bangalore in India, and at Culiacan in Mexico. Data is awaited for out stations. At ICRISAT, Patancheru ICCs 708, 3631, 6816, 8950, and 16903 (2.9-3.3 t ha $^{-1}$) were top five accessions with greater seed yield than all the five control cultivars (1.2-2.8 t ha $^{-1}$). ICC 16309 (42 days to 50% flowering and 105 days to maturity) was early flowering and early maturing than high yielding controls ICCV 10 (45 and 110 days) and Annigeri (45 and 108 days)

Pigeonpea: Pigeonpea mini core collection consisting of 146 accessions was evaluated with four control cultivars (ICP 11543, ICP 6971, ICP 8863, ICP 7221) in augmented designed trials at Patancheru, Dholi, Bangalore, Kanpur, Khaegone, Sardar Krishinagar, and Badnapur in India, and at Dubai in UAE. Data is awaited for out stations. At ICRISAT, Patancheru, ICPs 3451, 4167, 6123, 8255, and 14722 (2.6 – 2.8 t ha $^{-1}$) produced greater seed yield than the best control cultivar ICP 8863 (2.0 t ha $^{-1}$).

Groundnut: 184 accessions of groundnut mini core collection were evaluated with four control cultivars (Gangapuri, M 13, ICGS 44, ICGS 76) in augmented designed trials at Patancheru, Jalgaon, Raichur, Durgapura, and Aliyanagar in India, Qingdao in China, and two sets at Lilongwe in Malawi. Data is awaited for out stations. At ICRISAT, Patancheru ICGs 3992, 10185, 12625, and 14482 (4.3 – 4.6 t ha $^{-1}$) had greater pod yield than the high yielding control cultivar M 13 (4.2 t ha $^{-1}$). ICGs 115, 397, 3746, 10890, and 15042 (>75%) had greater shelling turn over, and ICGs 4746, 5662, 6993, and 9905 had greater seed size (100-110 g).

HD Upadhyaya and CLL Gowda

Milestone C.4.1.2: Core collection of pearl millet evaluated in multilocations in India (HDU/CLLG/NARS, 2008)

Sets of pearl millet core collection consisting of 504 accessions and four control cultivars were sent to All India Pearl millet improvement Program, Mandor for evaluation at five locations in India. Data is awaited from these locations. The preliminary analysis at ICRISAT, Patancheru revealed that IPs 9496, 11584, 15010, 17554, and 17566 (60-62 days) were early flowering, IPs 8130, 10401, and 12650 (30-56 cm) were short statured good for mechanical management and IP 12570 (210 cm) was good for fodder. IPs 5207, 5447, 10290, 11457, and 12338 (56 – 64 cm) had long spike length. IPs 7440, 8000, 10456, 10471, and 17753 (35-40 mm) had thick spikes.

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)

300 accessions of chickpea reference set are being phenotyped for yield and other important agronomic and morphological descriptors along with five control cultivars. Data recording is in progress.

HD Upadhyaya, N Lalitha and CLL Gowda

Output target C.5: Mini core and or 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

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)

Chickpea mini core evaluated for diseases resistance: Chickpea mini core subset consisting of 211 accessions were reevaluated to confirm their resistance to ascochyta blight (AB), botrytis gray mold (BGM), fusarium wilt (FW), collar rot (CR) and dry root rot (DRR) diseases under controlled environment conditions at ICRISAT-Patancheru. Standardized optimum conditions for individual diseases were used for evaluation. Accessions were categorized and grouped based on their reaction to each disease in both tests.

Resistance to AB: High levels of resistance to AB were not found in mini core subset. However, three desi type accessions ICC 1915, ICC 6306, ICC 11284 were identified as moderately resistant (3.1 to 5 rating) to AB. Among these three accessions, ICC 6306 had a 100 seed mass of 25 g while the rest had <20 g.

Resistance to BGM: Absolute resistance to BGM was not found in mini-core subset. But, 55 accessions had moderately resistant reaction (3.1 to 5 rating). Of these moderately resistant accessions, 33 were Kabuli type, 17 were desi and remaining five of intermediate type. Of these Kabuli accessions, ICC 8151 and ICC 14199 were very bold with a 100 seed mass of around 58 g. Among desi types, one accession ICC 13124 had highest 100 seed mass of 35.4 g.

Resistance to FW: Several accessions had high levels of resistance to FW. Twenty one accessions were found asymptomatic and 25 accessions were identified as resistant (<10% mortality) to FW infection. Among asymptomatic accessions, one accession ICC 8058 was Kabuli type with 100 seed mass of 33.8 g. Two kabuli accessions, ICC 13816 and ICC 13441 with 100 seed mass of 29 g and 16.7g respectively were identified among resistant group.

Resistance to DRR: Only six accessions, ICC 1710, ICC 2242 (desi type), ICC 2277, ICC 11764, ICC 12328, and ICC 13441 (Kabuli type) were found moderately resistant (3.1 to 5 rating on 1-9 rating scale) to DRR. Of the promising Kabulis, ICC 11764 and ICC 12328 had a 100 seed mass of 28.8 g and 27.5 g respectively.

Resistance to CR: All the accessions of the mini core sub set were found susceptible to collar rot.

Multiple disease resistance: Among the mini core accessions, no line was found resistant or moderately resistant to more than two diseases in both tests. 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 was not observed in any of the accessions tested. Two accessions, ICC 11764 and

ICC 12328 had a moderate 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, 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)

Fusarium wilt and SM resistance in mini core accessions: One hundred and forty six mini core accessions were evaluated for combined resistance to wilt and sterility mosaic disease (SMD) under artificial epiphytotic conditions using standard field evaluation techniques at ICRISAT-Patancheru. Threshold level of wilt fungus, Fusarium udum was maintained by incorporating chopped wilted pigeonpea plants in the sick plot every year. Each and every plant of test entries planted in wilt sick plot, were leaf inoculated with SM infested leaves using leaf staple technique at two-leaf stage for successful SM infection. 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. Additionally, natural incidence of Phytophthora blight (PB) was also recorded at seedling stage during the current season as there were frequent and continuous rains.

Only two mini core accessions, ICP 11015 and ICP 14819 had a combined resistance (< 10%) to both wilt and SMD. Nine accessions, ICPs 7869, 9045, 11015, 11059, 11230, 11281, 11910, 14819 and 14976 were asymptomatic and 19 accessions were resistant to SM. Eight accessions, ICPs 4903, 6739, 6815, 7057, 10559, 11015, 14638 and 14819 were asymptomatic and 70 were found resistant (< 10% disease) to natural incidence of PB.

S Pande and HD Upadhyaya

Evaluation of pigeonpea mini-core collection for resistance to *Pigeonpea sterility mosaic virus* (PPSMV) under glasshouse conditions: During 2006, 120 of the 146-pigeonpea mini core accessions were evaluated under greenhouse conditions against PPSMV-P isolate at ICRISAT, Patancheru. Thirty seed of each accession was sown in plastic pots in three replications and maintained in a greenhouse at ICRISAT, Patancheru, India. Plants were inoculated with PPSMV at 2-leaf stage with the viruliferous mites, and they were monitored for symptom type and percent incidence at 2 weekly intervals. Percent infection was estimated based on visual symptoms and the virus detection by double antibody sandwich ELISA using PPSMV-P polyclonal antibodies, at 20, 40 and 60 days post inoculation (dpi). Pigeonpea cvs. ICP8863 and ICP7035 were used as susceptible and resistant controls, which showed 100 and 0 percent infection at 60 dpi, respectively. Of 120 mini-core accessions, 9 accessions (ICP# 14976, 16264, 7869, 9045, 11910, 11015, 14801, 13579 and 15049) showed only ringspot symptoms (localized reaction, no systemic spread of the virus and no sterility) in 5 to 16% of the plants. Systemic leaves of the infected plants tested negative to virus in ELISA, indicating that virus multiplication is restricted to the inoculated leaves. Remaining accessions showed 22 to 100% infection and the plants developed severe mosaic symptoms at 60 dpi. This study indicates narrow base of resistance to PPSMV in the pigeonpea mini-core. This study is the second year evaluation of pigeonpea mini-core for PPSMV resistance. The resistant accessions provide entry point for further evaluation of genotypes for SMD resistance. All the resistant/tolerant accession will be tested against various PPSMV isolates in India.

PL Kumar, HD Upadhyaya and F Waliyar

Milestone C.5.1.3: Mini core collection of pigeonpea germplasm evaluated for resistance to Helicoverpa (HCS/HDU/KBS, 2009)

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)

Milestone C.5.1.5: Sorghum mini core set evaluated for resistance to grain mold and anthracnose (RPT/RS/HDU, 2010)

Milestone C.5.1.6: Pearl millet core set evaluated for resistance to downy mildew and rust (RPT/RS/HDU, 2011)

Milestone C.5.1.7: Finger millet core set evaluated for resistance to foliar and neck blast (RPT/RS/HDU/CLLG, 2010)

Milestone C.5.1.8: Foxtail core set evaluated for resistance to blast disease (RPT/RS/HDU/CLLG, 2012)

Milestone C.5.1.9: Identification and evaluation of trait specific germplasm in finger millet and foxtail millet core collections (CLLG/HDU, 2008)

Finger millet: We evaluated 20 finger millet accessions with four control cultivars in a replicated trial. IEs 2340, 3194, 3790, 4974, and 6142 (116.7 – 188.3 cm) were significantly taller than the tallest control PR 2 and can be a source for feed and fodder. IEs 2498 and 4974 (56.7 – 61.7 mm) had wider inflorescence than the widest control RAU 8 ((55.0 mm). IEs 2498, 2683, and 2983 (10.7 – 11.3) have greater width of the longest finger than the best control PR 202 (10.00 mm). IEs 2498, 2578, 2887, 2903, and 4974 (11.1 – 13.4 g 1000 seed weight) had significantly greater seed size than the large seeded control RAU 8 (8.6 g). IEs 94, 2578, 3790, 3802, 4974, and 6236 (2.01 – 2.61 t ha^{-1}) were good for grain yield.

Foxtail millet: We evaluated 20 foxtail millet accessions with four control cultivars in a replicated trial. 11 accessions (38 – 45 days) flowered significantly earlier than the earliest control ISe 375 (56 days). ISes 1258 and 1658 (38 days) were the earliest accessions. ISes 769 and 1434 (159.3 – 161.3 cm) were significantly taller than the tallest control Ise 1541 (146.7 cm). ISes 1433 and 1434 (3.0) had significantly greater number of basal tillers than all the four controls (1.0-2.0).). ISes 1433 and 1434 (234.7 – 239.3 mm) had significantly greater inflorescence length than all the four controls (131.7 – 198.7 mm). ISe 1434 (2.06 t ha^{-1})) had significantly greater grain yield than all the four controls (0.81 – 1.53 t ha^{-1}).

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/LK/HDU/CLLG/PMG/RKV/KBS, 2007)

Chickpea screening: The screening that was performed in 2004-05 was repeated in 2005-06. We had a good agreement between the yield under salinity data of the two years (R^2 = 0.40). There was over a 6-fold range of variations in seed yield under salinity, indicating that this range of variations would be more suitable for breeding salinity tolerant lines. From the 2 consecutive trials, the most contrasting genotypes were selected and used to develop crosses, in relation with the chickpea breeding group. To select the contrasting genotypes, we also tried to match the phenology of the parents used. We tried also to select parents with good yield potential under control conditions, knowing that yield potential explains a part of the performances under salinity. From the two years of trial, about 55 entries were dispatched to UWA (Australia) in the frame of the COGGO-funded project. Purpose is to test them for salinity in the Australian conditions. The mini-core collection of chickpea has also been sent to 2 locations in India (PAU, Ludhiana, Punjab and CSSRI, Karnal, Haryana), in collaboration with Dr Sandhu (PAU) and Dr RK Gautham (CSSRI), for field testing. Data from the 2004-05 were presented at the Australian Society of Agronomy meeting (Perth 10-14 Sept 06) and are being published in Field Crop Research.

V Vadez, L Krishnamurthy, HD Upadhyaya, CLL Gowda,
PM Gaur and RK Varshney

Groundnut screening: The groundnut screening for salinity tolerance from 2005 was repeated at same time in 2006 (Sowing in April) and under the same conditions. This time, we cultivated plants under saline and control conditions until maturity and could therefore assess the yield. The range of variation for pod yield under salinity was about 6-7-fold between the most and the least tolerant genotypes. A list of tolerant and sensitive genotype from that screening is available on request. From that screening, we would be able to select the most promising for field-testing in Orissa in 2007-08. Unlike previous finding in chickpea, we found no relation between pod yield under salinity and pod yield under control, meaning that salinity tolerance for pod yield production under salinity was not related to the yield potential of groundnut. We found a modest relation between the ratio of pod yield (pod yield salinity / pod yield control) and the ratio of shoot biomass at maturity. This indicated that, although genotypes able to develop relatively more biomass under salinity were somewhat more likely to achieve a better relative pod yield, the screening for salinity tolerance is more reliable if based on the assessment of pod yield under salinity. Compare to control, the number of pod per plant was reduced by about 50%. Pod weight under salinity was further reduced under salinity, being only 30% of that under control. This result showed that not only the success of the reproductive process under salinity (proxied by the number of pods) was a key to high yield, but also the ability of plant to fill up these pods. A repeat of that screening is on going; from which a robust set of tolerant/sensitive genotypes will be identified for further testing. Crosses are also being made to develop segregating populations.

V Vadez, HD Upadhyaya, SN Nigam and RK Varshney

Pigeonpea screening: Data from the 2005 experiment were processed and analyzed. Here, we have assessed the morphological and physiological variation in pigeonpea for salinity tolerance in 300 genotypes, including the mini core collection of ICRISAT, wild accessions and land races from putatively saline prone areas worldwide. There was 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^+ accumulation in shoot showed that more tolerant cultivated materials accumulated less Na in shoot (Fig 6). 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. It was interesting to notice that *C. scarabaeoides* also provided a large range of sensitive materials. The minicore 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 the pigeonpea screening done in 2005 was performed. Unfortunately, the trial failed because of soil quality used for that experiment (we noticed too late the poor fertility of the soil lot that was allotted to us and saline treated plant failed to make it to harvest).

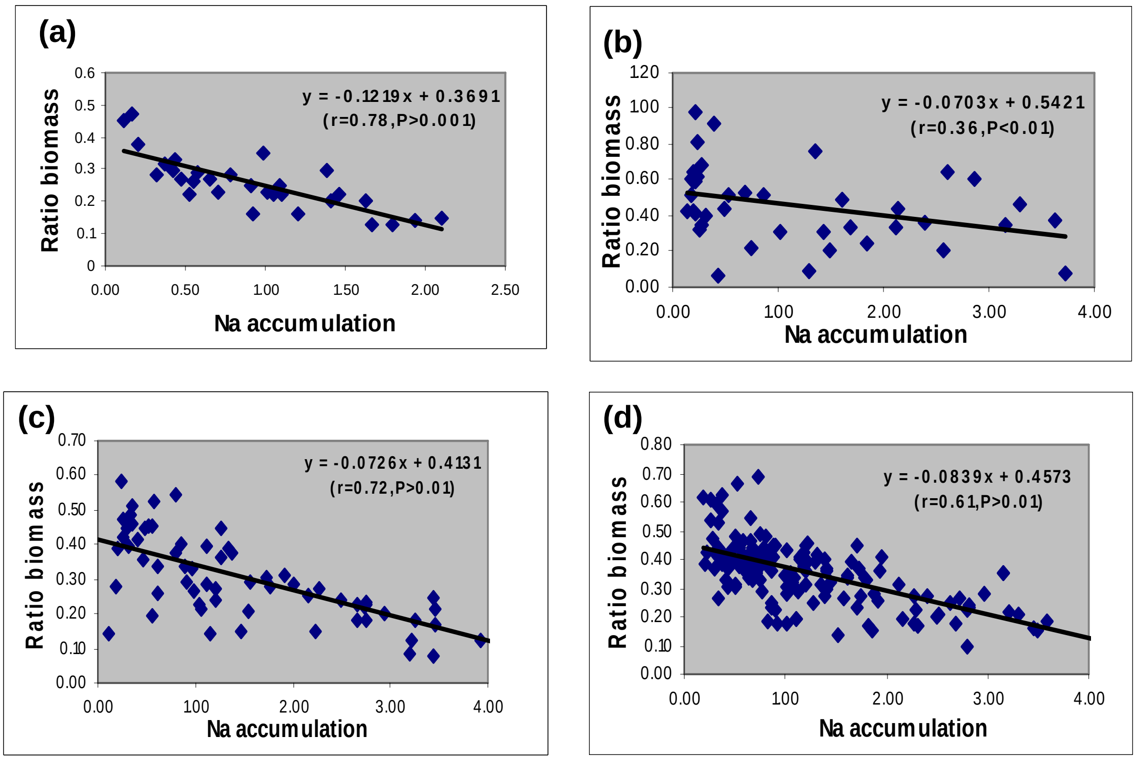


Fig 6. Simple linear correlation between the ratio of biomass (biomass under salinity divided by biomass under control) and Na^+ accumulation in shoot: (a) with a treatment of 1.34 g NaCl kg^{-1} soil in six genotypes of different maturity group, (b) in wild species (c) in selected landraces from saline areas (d) in the minicore collection. Data are the mean of 5, 3, 3, and 3 replicated data of each genotype, for (a), (b), (c) and (d) respectively.

V Vadez, HD Upadhyaya, KB Saxena, CLL Gowda and RK Varshney

Milestone C.5.2.2: Chickpea mini core salinity evaluation data analyzed (VV/LK/HDU, 2008)

Salinity is an ever-increasing problem in agriculture worldwide, especially in South Asia (India, Pakistan) and Australia. A screening of 263 accessions of chickpea, including 211 accessions from ICRISAT's mini-core collection (10% of the core collection and 1% of the entire collection), was performed and showed, overall, that the large variation in salinity tolerance in chickpea was explained by differences in sensitivity at reproductive stages. Data showed a six-fold range of variation for seed yield under salinity, with several genotypes yielding 20% more than a previously released salinity tolerant cultivar. The range of variation in yields under salinity was similar in both kabuli and desi chickpeas, indicating that breeding for salinity tolerance can be undertaken in both groups. Among the genotypes evaluated, desi genotypes had higher salinity tolerance than kabuli genotypes. A strong relationship was found between the seed yield under salinity and the seed yield under a non-saline control treatment, indicating that the seed yield under salinity was explained in part by a yield potential component and in part by salinity tolerance *per se*. Seed yields under salinity were therefore computed to separate the yield potential component from the residuals that accounted for salinity tolerance *per se*. The residuals were highly correlated to the ratio of seed yield under salinity to that of the control, indicating that both parameters can be used to assess salinity tolerance. A similar ratio was calculated for shoot dry weight at 50 days after sowing. However, no significant correlation was found between the shoot dry weight ratio and the yield ratio, indicating that differences in salinity tolerance among genotypes could not be inferred from measurements in the vegetative stage. The major trait related to salinity tolerance was the ability to maintain a large number of filled pods, whereas seed size was similar in tolerant and sensitive genotypes. Salinity tolerance was also not related to the Na^+ or K^+ concentrations in the shoot. A journal article has been submitted to the field crops Research.

V Vadez, L Krishnamurthy and HD Upadhyaya

Milestone C.5.2.3: Sorghum mini core and pearl millet reference set screened for salinity tolerance (VV/LK/HDU/CTH/KNR, 2008)

First screening of a part of the mini-core collection of sorghum has been initiated (October 2006) and data will be available in 2007. The full collection should be screened in 2007-08.

V Vadez, L Krishnamurthy, HD Upadhyaya, CT Hash and KN Rai

Milestone C.5.2.4: Reference sets of chickpea, pigeonpea, and groundnut evaluated for salinity (VV/LK/HDU/RKV, 2010)

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)

We have screened 440 groundnut genotypes for TE, under progressive soil drying conditions, during the Feb-April 2006 period. These 440 genotypes included the mini core collection of groundnut (184 accessions), other germplasm lines, control cultivars, and elite breeding lines. The data show an impressive range of variation between the top and the bottom ranked groundnut genotypes for transpiration efficiency (TE, g kg^{-1} water transpired). In that experiment, TE varied between about 0.3 g kg^{-1} water transpired and 3.6 g kg^{-1} water transpired. About 90% of the genotypes (excluding the bottom 40 and top 10 in the ranking of TE) were in a range of TE between 0.5 and 2.5 g kg^{-1} water transpired, i.e. still a 5-fold range of variation. Ten genotypes had TE higher than 2.5 g kg^{-1} water transpired and one genotype reached 3.6 g kg^{-1} water transpired. A repeat of that experiment will be carried out in 2007. TE was also assessed under well-watered (WW) conditions in the mini core collection of groundnut, plus with controls (200 accessions). It has been reported in the literature that there is a good relation between TE measured under water stress and TE measured under well-watered conditions, from which it has been inferred that mesophyll efficiency differences were the major reason for differences in TE. However, this relation has been worked out with a very narrow range of genotypes and fully overlooks the potential role of stomatal regulation in the determination of TE differences. Relation between TE under water stress (WS) and under well-watered conditions with a larger set of genotype was also assessed. TE was overall higher under WW conditions (1.92 g kg^{-1} water transpired) than under WS (1.44 g kg^{-1} water transpired). We found significant relation between TE under water stress and TE under well-watered conditions. However, the correlation coefficient was 0.32 only, indicating that it would be advisable to consider TE under WS and WW conditions separately. Analysis needs to be done to test the significance of genotype x moisture interaction.

V Vadez, L Krishnamurthy, HD Upadhyaya,
RK Varshney, and, CL.L Gowda

Milestone C.5.3.2: Sorghum mini-core (or reference) set screened for TE (VV/HDU/CTH/BVSR, 2009)

Milestone C.5.3.3: Groundnut mini-core screened for root traits (VV/HDU/RKV/CLLG, 2010)

The protocol to screen groundnut for root traits is being worked out with a small set of genotypes to optimize the cylinder system that will be used. Screening for root traits in groundnut will be based both on transpiration values (using a lysimetric system) and on root parameters (max depth, length density at different depth).

V Vadez, HD Upadhyaya, RK Varshney and CLL Gowda

Milestone C.5.3.4: Sorghum mini-core (or reference set) screened for root traits (VV/HDU/CTH/BVSR, 2011)

The protocol to assess root traits in sorghum is also being worked out. Cylinders currently used to assess root traits in sorghum are 16 cm in diameters and very likely 25 cm diameter cylinder will be used. As for groundnut (Milestone C.5.3.3), the assessment would be a combination of lysimetric measurements and root characteristics.

V Vadez, HD Upadhyaya, CT Hash and BVS Reddy

Milestone C.5.3.5: C ¹³ in chickpea analyzed at JIRCAS (JK/HDU/LK/PMG/IIPR-Kanpur/JIRCAS-Japan, Annual)

Analysis of $\delta^{13}C$ was performed in Japan International Research Center for Agricultural Sciences (JIRCAS), Tsukuba, Japan with use of an isotope ratio mass spectrometer (IRMS), ThermoFinnigan Delta XP^{plus}, Hamburg, Germany, connected with an element analyzer, Carlo Erba EA Flash 1112, Milan, Italy. Total carbon in leaf samples were incinerated in a furnace of EA and separated as to be pure CO_2 gas. A small quantity of the gas was introduced to IRMS to measure the ratio of $^{13}CO_2/^{12}CO_2$ as the different mass weight of 45/44 to obtain $\delta^{13}C$ (‰). There was a significant difference in $\delta^{13}C$ among the 10 chickpea genotypes, and the $\delta^{13}C$ in stress condition was a significantly higher than it in the control. A genotype of ICC 5337 showed the highest $\delta^{13}C$ (-26.0‰) in the stress condition. ICC 4958, which is well known as drought resistance variety, showed superior $\delta^{13}C$ than the other genotypes at the 2nd (-27.2‰) and highest (-28.4‰) in the stress and control condition, respectively.

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)

The genotype by irrigation (G x I) interaction was significant, which indicates that the each genotype had different reaction on $\delta^{13}C$ between the well watered and drought environments. A significant positive correlation between $\delta^{13}C$ and TE was observed ($r = 0.857$, $p<0.01$) under the stress condition. This relationship agrees with the theoretical relationship between $\delta^{13}C$ and TE as observed in several other legumes. However, no significant correlation was observed between them when the plants were grown under well watered condition. This would indicate that the ^{13}C discrimination is occurred in the chickpea when they have been subjected to soil moisture stress.

J Kashiwagi, HD Upadhyaya, L Krishnamurthy, PM Gaur,
IIPR-Kanpur and JIRCAS-Japan

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)

Milestone C.5.4.2: Chickpea reference set field evaluated for drought response (JK/LK/ HDU/NL, 2008)

Milestone C.5.4.3: Chickpea reference set genotyped with 100 SSR markers (HDU/NL/RKV/JK/LK/SC, 2008)

A set of more than 300 (TA, TS, TR, TAA, GA, GAA, STMS, AGL series) SSR markers, well distributed over the chickpea genome have been screened initially on two diverse genotypes of chickpea (Annigeri, ICCV2). Subsequently, sets of polymorphic and high quality markers were identified. In order to improve the efficiency of genotyping multiplexes for all markers are being optimized

The reference collection consisting of 300 accessions has planted in field on 1st November 2006 with 20 seeds per accession. The wild accessions were first sown in incubator and transplanted in the field. DNA was extracted at 22nd day from leaf tissue by using high – through put method and quality checked by using agarose gel electrophoresis. Quantification of DNA concentration has been done with fluorescence detector and diluted to 5 ng/ul as working sample.

The genotyping of reference collections of chickpea accessions will be started with optimized multiplexes by using Genetic Analyzer (ABI 3100).

HD Upadhyaya, N Lalitha, RK. Varshney, J Kashiwagi, L Krishnamurthy and S Chandra

Milestone C.5.4.4: Groundnut reference set phenotyped for traits associated with drought resistance (VV/HDU/RKV, 2009)

Milestone C.5.4.5: Groundnut reference set genotyped with 100 SSR markers (HDU/RKV/DH, 2010)

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 Allelic Diversity on Orthologous Candidate genes (ADOC), identification of drought responsive genes is underway. Currently, DREB1a and DREB2a genes are being identified in chickpea by using *in silico* analysis (see Output Target D.3).

RK Varshney, HD Upadhyaya, B Jayashree 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)

Milestone C.5.4.8: Diversity analyzed for the molecular markers and markers associated with drought traits identified (HDU/RKV/DH, 2012)

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)

The global pearl millet core collection was grown in a replicated trial at the ICRISAT Sahelian Center near Niamey, Niger, in the Rainy Season 2006. Ms Jenny Coral Padilla, MSc student from University of Hohenheim, Stuttgart, Germany, was involved in the characterization. Data analysis and MSc thesis write-up are underway.

BIG Haussmann and HD Upadhyaya

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)

Finger Millet: 506 finger millet germplasm accessions of core collection from India were planted and characterized at Kiboko (2005/06) and Alupe (April-Sept 2006). Preliminary principal component analysis results from Kiboko based on 15 quantitative traits showed 57% of the variability in the germplasm accounted for by the first two principal components (PCs). High positive loadings on PC1 were contributed by days to 50% flowering, plant heights, leaves per plant, leaf lengths, leaf widths, neck lengths, peduncle length, stem diameter and high negative loadings from heads per plant, number of nodal tillers, and number of productive tillers. Though generally 6 cluster groups were observed, 3 distinct clusters were evident with no distinct pattern of grouping based on country of origin as accessions from different countries were found in almost all clusters. Further analysis including all traits (both qualitative and quantitative) from Kiboko and Alupe will done and reported fully in the 2007 archival report

MA Mgonja, E Manyasa, E Muange and HD Upadhyaya

Milestone C.6.2.2: Promising and adaptable materials identified and distributed and evaluated in regional finger millet trials the ESA (MAM/SGM, 2008)

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 contents in a sorghum core collection from at least 2 ABS target countries established (MAM/SGM/HDU, 2008)

The African Bio-fortified Sorghum Project intends to develop transgenic sorghum varieties that will deliver essential amino acids; lysine, threonine, methionine and tryptophan; vitamins A and E; iron; and zinc which are deficient in sorghum to African populations in the arid and semi-arid tropics. Field work has been initiated to document diversity of the above traits in sorghum germplasm and close gaps in sorghum germplasm from the at least two ESA countries. In 2006, using GIS we mapped sorghum collection sites in order to identify collection gaps. Further we examined ABS target countries in order to identify the major collection gaps within those countries targeting planned collection missions. We used data available at ICRISAT genebank and in addition we sought for information on collections that have been done by the national gene banks to update the database. The National Gene bank of Kenya provided us with 994 data sets while the Genetic Resources Unit of the National Department of Agriculture of South Africa provided us with 257 data sets. A core collection of sorghum from 5 ABS target countries has been formed and it contains 426 accessions. This collection was planted at Kiboko, Kenya in November 2006 for agronomic characterization. Additional accessions that are known to have great variation in the ABS traits of interest were included for characterization. The National Gene bank of Kenya, KARI and ICRISAT carried out a joint collection mission in July-August 2006 and a total of 154 accessions were collected from Western, Rift Valley, Eastern and Coastal provinces of Kenya. The collections have been incorporated in the GIS map of Kenya and have been planted for morphological characterization at KARI-Embu. Saturated GIS maps for Kenya sorghum collections are therefore available

MA Mgonja, SG Mwangi and HD Upadhyaya

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)

Milestone C.6.4.2: Wild Arachis evaluated for target traits (GRD, ELS, aflatoxin resistance) at hotspot locations in ESA (ESM/HDU etc. 2009)

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)

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)

Groundnut: Multiplied the seed of 21 early maturing, 18 drought tolerant and 60 high yielding combined with other traits of economic importance groundnut accessions for distribution to partners.

Chickpea: Multiplied the seed of 28 early maturing and 18 droughts tolerant, 16 large-seeded kabuli, 39 high yielding combined with other traits of economic importance, 29 salinity tolerant chickpea accessions for distribution to partners.

Mini core: Multiplied the seed of chickpea, pigeonpea, and groundnut mini core collections for distribution to partners.

HD Upadhyaya, CLL Gowda, RP Thakur and NBPGR

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)

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)

We produced 18 F_1 diploid hybrids between different accessions of five A genome and five B genome Arachis species. Some of the hybrids did not set seeds in spite of profuse peg formation and only five hybrids produced seeds (F_2 seeds). Attempts are being made to obtain seeds from other crosses too.

N Mallikarjuna, HD Upadhyaya and DA Hoisington

Milestone C.9.1.2: Tetraploid hybrids between different genomes generated and skeletal map constructed (NM/RKV/HDU/DH, 2008)

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)

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)

F_2 plants from *A. hypogaea* x *A. chiquitana* ICG 11560 (section Procumbentes) and *A. hypogaea* x *A. kretschmeri* IG 8191 (section Procumbentes) crosses were used to produce back cross progenies with the cultivated species. Most of the pods on progenies were single seeded. Efforts will be directed to generate large numbers of seeds.

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)

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)

BC_3 plants (*Cajanus platycarpus* x *C. cajan*) are being crossed with recurrent cultivated parent in the glasshouse, as BC_3 plants do not set seeds from self-pollinations. Twenty three lines of fertile backcross progeny (BC_4) between *C. platycarpus* x *C. cajan* were generated and planted in the field for seed increase. BC_4 have set seeds from self-pollinations.

N Malikarjuna, DA Hoisington and HD Upadhyaya

Milestone C.9.2.2: Generate variation for desirable characters using Cajanus platycarpus (NM/HDU/RKV/DH/KBS, 2009)

BC_4 plants from the cross *Cajanus platycarpus* x *C. cajan* were screened for variability under field conditions and variability was observed for plant type, number of secondary branches, vegetable type of pod characteristics, days to flowering, profuse pod set, male sterility, and plant height. The experiment will be repeated to verify if these characters are heritable.

N Malikarjuna, HD Upadhyaya, RK Varshney and DA Hoisington

Output target C.10: Data management infrastructure development (2010)

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/DAH/SS/RKV/DK/SV, 2007).

The beta testing of the LIMS system is in progress at ICRISAT. The respective data producers have uploaded genotyping data for the composite core collections of chickpea and sorghum into the system. The application functionality and user interfaces continue to be modified to suit user requirements. The LIMS application has also been extended and adapted for use at ICRISAT/IITA/ILRI - Nairobi and IITA-Ibadan. A workshop was conducted at ICRISAT-Nairobi to demonstrate the software to potential users and obtain feedback. The software has also been shared with several universities and private partners under the terms of the GNU general public license.

B Jayashree, DA Hoisington, S Senthilvel, RK Varshney, DKiambi and S de Villiers

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 LIMS –ICRIS adaptor allows the flow of genotyping data from the LIMS application into the ICRIS database. The database is expected to integrate genotyping information with genetic resource and phenotype information. Progress was made this year in coding for generic middleware to this database to bring it in compliance with the GCP(generation challenge program) platform. This will allow for the database to become interoperable with other databases and repositories available in the public domain. A GCP platform compliant data source API (application program interface) is also being developed that will allow data consumers such as publicly available analytical or visualization tools to access data within the database.

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)

Milestone C.10.2.3: Curation of data with involvement of data providers.

Output target C.11: Development of data analysis tools

Activity C.11.1: iMAS a decision support system for marker aided breeding.

Milestone C.11.1.1: Further development and testing of application (SC/DH/JB, 2007).

The goal of this two-year project (2005-06) was to develop an integrated decision support system, called **iMAS**, to seamlessly facilitate marker-assisted plant breeding by integrating freely available quality software involved in the journey from phenotyping-and-genotyping of genetic entities to the identification and application of trait-linked markers, and providing simple-to-understand-and-use online decision guidelines to correctly use these software, interpret and use their outputs. The project was structured into nine activities, namely: **A1**: Analyze potentially useful free software, **A2**: Select software for inclusion in iMAS, **A3**: Develop iMAS system, **A4**: Develop & incorporate online decision guidelines, **A5**: Test iMAS system, **A6**: Refine iMAS system, **A7**: Develop iMAS user manual/tutorial, **A8**: Release of and Training in iMAS, **A9**: Consultation and support.

Five different software have been integrated in this pipeline along with online decision support and the integration of two more software is in progress in 2006. Integrated software include IRRISTAT, Gmendel, PlabQTL, POPMIN and GGT while the integration of WinQTLCartographer and TASSEL is in progress. The pipeline has been modified to incorporate user comments, two major workshops were conducted accommodating over 40 scientists from the NARS besides ICRISAT staff and interested private partners to test the application. Besides, project partners reviewed the application and their suggestions are being incorporated.

S Chandra, DA Hoisington and B Jayashree

Activity C.11.2: High performance computing toolbox.

Milestone C.11.2.1: Extension of existing tools with user friendly interfaces (JB/RKV/DH/SC and others).

The pipelines and standalone software available within the comparative genomics and population genetics toolboxes on the high performance computer have been extended through 2006. The comparative genomics toolbox now includes a suite of parallelized programs for marker mining and detection from large public datasets and open source software for comparative sequence analysis and phylogeny. The population genetics toolkit includes a parallelized version of the program 'structure' with user interfaces and visualization software along with format conversion tools for a variety of popularly used analysis software.

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)

Pipelines for the SNP, from public EST data are now available on HPC (http://hpc.icrisat.cgiar.org/pbsweb).

Output D: RILs of staple crops and small millets developed/assembled and DNA extracts conserved and distributed

MTP Output Targets 2006
Genetic diversity of chickpea composite collection determined

RILs of groundnut and chickpea (WUE, diseases) assembled

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/CLLG, 2006)

ICRISAT has developed and is maintaining three RIL populations (Annigeri × ICC 4958, ICCV 4958 × ICC 1882, ICCV 283 × ICC 8261) for root traits, two for fusarium wilt resistance (ICCV 2 × JG 62, WR 315 × C 104) and one for *Helicoverpa* resistance (ICC 505 EB x Vijay). We assembled three RIL populations for root traits and fusarium wilt resistance from other institutes during 2006. These include two intraspecicfic RIL populations, JG 62 x ICC 4958 (fusarium wilt resistance and root traits) and Vijay x ICC 4958 (root traits) from National Chemical Laboratory, Pune, India and one interspecific RIL population, *Cicer arietinum* (ICC 4958) *x C. reticulatum* (PI 489777) (root traits) from Washington State University, Pullman, USA. The seed of these RILs are being multiplied during the 2006/07 crop season and would be submitted to the genebank.

Milestone D.1.1.2: RILs of groundnut (WUE - 4, rust – 2, and LLS – 2) assembled (SNN/HDU, 2006)

We developed four RIL populations, two each for late leaf spot (ICGV 99001 x TMV 2 and ICGV 99004 x TMV2) and rust resistance (ICGV 99003 x TMV 2 and ICGV 99005 x TMV2). TMV 2 was used as susceptible parent for both rust and late leaf spots in all four populations. The four resistant parents were interspecific derivatives involving cultivated *Arachis hypogaea* (AABB genome, 2 n = 4 x = 40) and three wild *Arachis* species, *A. villosa*, *A. cardenasii*, and *A. stenosperma* (all A genome 2 n = 2 x =20). ICGV 99001 is an interspecific derivates from a cross between cultivated Robut 33-1 (subsp. *hypogaea* var. *hypogaea*) and *Arachis villosa*. ICGV 99003, ICGV 99004, and ICGV 99005 are interspecific derivates from three-way crosses between hybrids of two cultivated lines and wild species. ICGV 99003 was developed from crosses involving a hybrid of cultivated types with *A. stenosperma*. ICGV 99004 and ICGV 99005 were developed from a three way cross between hybrids of two cultivated types with *A. cardenasii*. The seeds of all four RIL populations are conserved in the genebank.

Milestone D.1.1.3: RILs of pigeonpea (one population of wilt resistance) assembled (KBS/HDU, 2008)

Milestone D.1.1.4: RILs of pearl millet (3 populations) assembled (CTH/HDU, 2008)

Milestone D.1.1.5: RILs of sorghum (grain mold – 2, stem borer –3, and shoot fly -2) assembled (BVSR/HCS, 2008)

Milestone D.1.1.6: TILLING population of pearl millet developed (RKV/CTH/DH, 2009)

To generate the TILLING population in pearl millet, the inbred line “P1449-2-P1” has been chosen, as it is one of the parental genotype of a mapping population (PT 732B x P1449-2-P1) developed and maintained at ICRISAT and segregates for plant height (*d2*), downy mildew resistance and stover grain quality. It is the tall parent, witch serves as a good source of downy mildew resistance for the improvement of local cultivars. The chemical mutagen ethyl methane sulfonate (EMS) was selected to develop the TILLING population, as it generates mostly single nucleotide polymorphisms or SNPs (in genes) and can be controlled to produce a high density of point mutations causing a variety of lesions including nonsense and missense mutations. After treating the seeds of the selected pearl millet inbred line with several concentrations (5 mM, 10 mM, 15 mM, 20 mM, 25 mM, 30 mM, 35 mM, 40 mM, 45 mM, 50 mM, 55 mM and 60mM), recommended in literature our results suggested that all the mutagen concentrations above 5 mM are lethal to the pearl millet genome. Subsequently a lower range of concentration of mutagen (1 mM, 2 mM, 3 mM, 4 mM, 5 mM, 6 mM, 7 mM, 8 mM, 9 mM, and 10 mM) for different treatment time (4 hrs, 8 hrs, 12 hrs) was used. As a result, finally about 2000 seeds each were treated with three mutagen concentrations i.e. 5 mM, 9 mM and 10 mM (each with 4 hrs) that should provide 60% 50% and 40% plants survived. The treated seeds were sown in 12" diameter pots and after about two weeks time, these plants were transplanted into field. In fields all plants were selfed and finally a total of 2,581 M1 lines have been harvested. These include 1169 lines from 5 mM, 737 from 9 mM and 675 from 10 mM. These lines will be advanced to M2 generation and another set of M1 lines will be generated.

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)

A set of contrasting genotypes for salinity tolerance identified and three crosses have been performed:

ICC 6263 (sensitive, DF 70) x ICC 1431 (tolerant, DF 69)
ICC 15802 (sensitive, DF 66) x ICC 9942 (tolerant, DF 63)
ICCV 2 (sensitive, DF 39) x JG 11 (tolerant, DF 40)

Parents used for these 3 crosses have been chosen based on the similarity in phenology (DF = days to flowering), since it was found that the number of days to flowering has some influence on the level of salinity tolerance in the conditions where we assess the materials. Diversity analysis using SSR markers is in progress.

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)

A group of genotypes showing good contrast for salinity tolerance has been identified for use in groundnut breeding. The choice of tolerant and sensitive materials has been based on a high and low pod yield under saline conditions, with all genotypes obtaining a good yield under control conditions.

V Vadez, SN Nigam, R.Aruna, RK Varshney and HD Upadhyaya

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)

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)

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)

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)

DNA was extracted from the chickpea reference collection consisting of the mini core collection.

Milestone D.2.1.2: DNA extracts of mini core and reference sets of groundnut and sorghum conserved (HDU/RKV/CTH/DH/CLLG, 2009)

Milestone D.2.1.3: DNA extracts of mini core set of pigeonpea conserved (HDU/RKV/CTH/DH/CLLG/KBS, 2010)

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)

Milestone D.2.1.5: Requested DNA samples of specific accessions distributed for utilization (HDU/RPT/RKV/DH/NBPGR, Annual)

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)

To identify the candidate genes for analyzing the sequence diversity, bioinformatics analyses in the first instance, a total of 20 DREB1A and 34 DREB2A non-redundant protein sequences were obtained through an in depth analysis of databases. The output alignment files from both ClustalW and MUSCLE were used for phylogenetic analysis and consensus primer design. The primers could be designed by CODEHOP for five blocks (A, B, C, D and E) in case of DREB1A and only for one block (A) in case of DREB2A. A total of 22 (9 forward and 13 reverse) primers for DREB1A and 13 (5 forward and 8 reverse) primers for DREB2A were designed and synthesized. All possible combinations (90 combinations in DREB1A and 40 combinations of DREB2A) were checked for amplification using 55-50^{0}C touch down PCR profile. In terms of getting homologous sequences in both species, single 'putative' amplicon was obtained with only 5 primer combinations; however, all these amplicons were smaller (<300 bp) in size. Therefore, good sequence quality data could not be obtained for any species by using these 5 primer combinations.

Besides degenerate primers, species-specific primers were designed using sequence information available in the public data domain. These species included *Oryza sativa*, *Arabidopsis thaliana*, *Medicago truncatula*, *Glycine max, Zea mays, Sorghum bicolor and Hordeum.* The specific primers for rice and soybean were designed according to the publications of Dubouzet et al. (2003) and Li et al. (2005) respectively.

The specific primers for *Arabidopsis*, Medicago*, Zea, Sorghum* and *Hordeum* were designed using PRIMER3 programme. However, the prominent fragments, to be used in sequenced, could not be obtained for any primer combination. Efforts are underway to identify the candidate DREB genes by using some other strategies.

RK Varshney, S Nayak, B.Jayashree,
HD Upadhyaya and Dave Hoisington

Milestone D.3.1.2: Allele specific sequence diversity in the reference set of sorghum studied (CTH/RKV/HDU/DH, 2011)

Use of above mentioned species-specific primers provided 'putative' DREB homologs in sorghum with groundnut DREB primer pairs (GmDREBb). Sequencing data of the prominent amplicons in seven diverse sorghum genotype however could not be matched with the known DREB genes with any species. Efforts are underway to identify the candidate DREB genes by using some other strategies.

RK Varshney, S Nayak, B Jayashree, HD Upadhyaya,
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, 2009)

A microsatellite or SSR (simple sequence repeat) enriched genomic DNA library of chickpea (ICC4958) has been constructed using pGEM-3Zf (+) vector in collaboration with the University of Frankfurt, Germany (Dr Peter Winter). The library has been enriched for (GA)n and (TAA)n microsatellites and a total of 359 clones have been collected. The plasmid DNA, however could be isolated for about 300 clones. These clones were sequenced for both strands, using T7 promater primer and SP6 primer of the pGEM-3Zf (+) vector. Analysis of sequence data with the *MI*cros*SA*tellite (MISA) search module provided about 220 clones containing at least one SSR. Based on the conserved flanking regions of the SSRs, the primer pairs are being designed and optimized.

RK Varshney, P Winter and DA Hoisington

In the case of pigeonpea, efforts have been initiated to generate the SSR enriched library from the pigeonpea variety "Asha". The genomic DNA library is being enriched for (CT)n and (TCG)n SSRs.

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, 2008)

Development of microsatellite markers for pearl millet is in progress in collaboration with Centre for Cellular and Molecular Biology (CCMB), Hyderabad (Dr Ramesh Aggarwal). By using an SSR enrichment method, developed at CCMB, >1000 genomic DNA clones enriched for SSRs have been developed. The isolation of plasmid DNA and sequencing is in progress. Sequencing of about 120 clones has already been completed and about 80 clones containing at least one SSR have been identified. The primer pairs have been designed for 64 SSRs based on the conserved flanking regions and are being optimized for amplification of SSR loci in pearl millet.

RK Varshney, R Aggarwal, T Mahender and DA Hoisington

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, 2010)

For developing the genetic maps in chickpea, currently three recombinant inbred line (RIL) mapping populations i.e. one interspecific (*C. arietinum* ICC4958 x *C. reticulatum* PI 489777) and two intraspecific (ICC4958 x ICC1882; ICC283 x ICC8261) are being used with newly developed SSR or existing SSR markers for identification of the polymorphic markers. The polymorphic markers will be used for genotyping the respective mapping populations.

RK Varshney, PM Gaur, J Kashiwagi and DA Hoisington

In pigeonpea, an interspecific F_2 population developed after crossing *C. cajan* (ICP28) x *C. scarabaeoides* (ICPW94) has been screened with the SSR markers developed at ICRISAT. About 30 polymorphic SSR markers have been identified between the parental genotypes of the mapping population. These genotypes are being screened with DArT (Diversity Array Technology) markers in collaboration with Dr Andrzej Killian (Australia) for identification of larger number of polymorphic loci.

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 e.g. David Bertioli (Catholic University/EMBRAPA, Brazil) and Steve Knapp (University of Georgia, USA) have been screened on the parental genotypes of the mapping population. However, so far about 120 polymorphic SSR markers. These polymorphic markers are being used for genotyping of the mapping population.

RK Varshney, V Vadez, SN Nigam, R Aruna 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, 2010)

A total of 627 markers (100 genomic SSRs, 60 EST-SSRs, 100 pearl millet SSCP-SNPs, 57 wheat SSCP-SNPs, 310 CISP-SNPs) were screened 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 tester lines (Tift 383 and Tift 186). Overall a total of 336 markers displayed polymorphism in at least one of 11 mapping populations. The polymorphic markers in different mapping populations ranged from 113 (Tift 23DB-1-P5 x WSIL-P8) to 151 (ICMB 841-P2 x 863-P3) with an average of 115 markers per population. Two mapping populations (i.e. ICMB 841-P2 x 863-P3 and 81B-P6 x ICMP 451-P8) are being advanced to RILs (at present F6 lines) and therefore in the first instance, these mapping populations will be genotyped with the polymorphic markers.

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)

A total of 523 isolates involving bacteria, fungi, and actinomycetes were added to the short to medium term storage, for further studies. All these were picked to represent diversity in a soil sample from a given crop-production system and had at least one agriculturally beneficial trait such as ability to solubilize rock phosphate, plant growth promotion, antagonism to plant pathogenic fungi, pathogenicity to insect-pests. Most of these were bacteria and were characterized further for confirmation of the traits they were picked for and to learn those with more than one beneficial traits. The traits studied were P-solubilization, antagonism to Macrophomina phaseolina (a soil-borne root rot fungus), siderophore production (indicator of plant growth promotion) and presence crystalline protein. Eight were positive for at least two traits and four (SRI77, EB24, SB26, HIB67) had crystal proteins of the type found in *Bacillus thuringiencis* (Table 8).

Table 8. Characterization of bacterial isolates for multiple beneficial traits

S. No	Isolate number	P-solubilization	Antagonistic to *M. phaseolina*	Siderphore production	Crystalline protein
1	SRI 77	-	-	-	+
2	SRI 151	+	+	+	-
3	SRI 156	+	+	+	-
4	SRI 158	+	+	+	-
5	SRI 178	+	+	+	-
6	SRI 229	+	+	+	-
7	SRI 305	+	+	+	-
8	EB24	-	+	ND	+
9	SB26	+	+	ND	+
10	HIB67	-	-	ND	+

ND = Not Determined

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)

No long-term storage could be undertaken due to malfunctioning of the Freeze-drier, an equipment needed for the purpose.

OP Rupela

Milestone D.5.1.3: Requested agriculturally beneficial microorganisms distributed to bonafide users for utilization (OPR, Annual)

Requests received were for Rhizobia, the nodule forming bacteria, and for those microorganisms with ability to help manage insect-pests. Twenty five vials of rhizobial cultures and 24 units (one unit is sufficient to cover one acre of land) of carrier based inoculants of different rhizobial strains were provided. Three vials and 75 units of lignite-based entomopathogens were also provided. The requests were from NARS scientists, partners of Biopesticides Research Consortium (BRC) and peer 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

Output 3A. Heterotic relationships identified and utilized within sorghum and pearl millet germplasm adapted to WCA conditions and appropriate broad-based breeding populations and hybrid parents and made available to NARS and other partners annually to maximise genetic gain from selection

MTP Output Targets 2006
Multi-location testing of 100 pearl millet factorial crosses and parental populations completed at 6 locations to determine heterotic patterns

Multiplication and advance to BC5 generation of short statured Guinea-race A/B pairs of sorghum for the first time in west Africa

Impact from varietal improvement of the local dryland cereals of West and Central Africa (WCA) has seemingly lagged behind that of other crops and other regions. In recent years the ICRISAT team in WCA has made systematic efforts to improve this situation, by reorienting its breeding efforts towards farmers' expressed needs and preferences, by integrating varietal improvement efforts with natural resource management research, enhancing local cereal seed systems efficiently; and by starting to exploit heterosis within the well adapted locally widely grown guinea race sorghums. During 2006 we have been able to identify a set of hybrids based on guinea race sorghum landrace parents, which have potential for adoption by farmers, as they provide stable and significant heterosis across a range of test locations, on-farm and on-station. Producing seed of these hybrids appears to be feasible after our first experiences.

We have indications for consistent patterns of heterosis between different groups of guinea race sorghums from West-Africa. Sets of accessions representing these different groups of germplasm are presently under going SSR based marker analysis.

ICRISAT strengthened its capacities in Pearl Millet Breeding in WCA by recruiting a Senior Scientist in 2005. The program has gained strength and momentum by attracting a range of special donor funded projects. Thus research on heterotic grouping, developing potential hybrid parental lines based on West-African pearl millet germplasm is well under way.

Regional collaboration among the cereal breeders of the main cereal producing countries has been strengthened. Planning workshops, joint trials, joint monitoring tours of specific trials sites, and a regular information exchange are creating new dynamics for reviving hybrid breeding efforts among our partners.

Output target 3A1: Access of NARS to pearl millet and sorghum diversity enhanced

For pearl millet 360 early to medium-maturing pearl millet accessions originating from West-Africa were evaluated in the rainy season 2006 at six locations across WCA (Senegal, Mali, Burkina Faso, Niger, Nigeria). Similarly, 64 long-duration accessions were evaluated in the same season at 3 locations in the Sudanian zone, or with supplemental irrigation (Senegal, Mali, Niger). Breeders and farmers in the different countries and stations evaluated and selected germplam lines for different agronomic and traits that could be important for processing or commercialization. While the network of breeders intends to select materials for studies on heterotic groups, and for the creation of new broader based populations, each breeder can select materials for their own program, or for direct use. Patterns of adaptation among the WCA landraces are being examined carefully. An initial analysis was published in International Sorghum and Millets Newsletter (ISMN).

Sorghum breeders in the region have received locally adapted breeding materials and newly characterized accessions of guinea race sorghums on request, for specific zones of adaptation, and for specific uses. New groups of germplasm are being evaluated for use in the regional selection program, as well as for direct use by national programs. At present a set of earlier flowering materials from northern Nigeria and Cameroon is being assessed for widening the diversity of available breeding materials.

Activity 3A1.1: Evaluate early-medium and late pearl millet and sorghum germplasm from various locations in WCA (in Niger, Nigeria, Burkina Faso, Mali and Senegal for adaptation to specific agro-ecological zone in WCA.

Milestones: At least 10 useful accessions or population crosses identified and used for creating broad-based pearl millet breeding-populations for recurrent selection programs (BIGH 2007)

360 early to medium maturity pearl millet accessions evaluated in the rainy season 2006 (RS 2006) at 6 locations all over WCA (Senegal, Mali, Burkina Faso, Niger, Nigeria); 64 late-maturing accessions evaluated in RS 2006 at 3 locations (Senegal, Mali, Niger); 100 factorial crosses among diverse pearl millet populations evaluated in the RS 2006 at 7 locations (in Senegal, Mali, Burkina Faso, Niger, Nigeria). Data entry and analysis is underway. Each country will identify 5-10 superior accessions/population crosses from their own and the partner's trials; these will then enter recurrent selection programs targeting specific rainfall zones.

BIG Haussmann

Adaptation patterns of pearl millet germplasm in WCA published (2008)
First year multi-location field trials were completed in RS 2006. Preliminary characterization data and geographic differentiation patterns for 280 pearl millet landraces from WCA were evaluated at Sadore (Niger) in RS 2005 and published in the ISMN.

BIG Haussmann

Activity 3A1.2: Regional nurseries of sorghum and pearl millet germplasm assembled and made available to WCA NARS.

Milestones: Results from initial regional germplasm evaluation compiled and made available to partners (2007)

The multi-character evaluation of the guinea-race sorghum core collection includes a range of yield component traits, traits related to adaptation, fertility restoration on the A1 cytoplasm for male-sterility as well as standard morphological characters. The results are presently being compiled for publication and dissemination. In addition to the core collection evaluation, we conducted an evaluation of predominantly earlier maturing guinea or intermediates race germplasm from Nigeria, Chad and Cameroon during the 2006 rainy season. Individual panicles were selfed, and selected from accessions with interesting trait combinations. The Nigerian accessions were also sent to Zaria for evaluation in Nigeria. The sorghum core collection established by CIRAD was evaluated for growth rate during the 2004 and 2005 rainy seasons. The data was analysed, and is being prepared for publication.

HFW Rattunde, B Clerget and E Weltzien with CIRAD

Seed of at least 10 selected pearl millet accessions multiplied and made available to partners (2008-11)
Germplasm accessions from across West-Africa were evaluated in 5 countries (see above). Scientists from partner NARS, and farmers from areas near the research station evaluated these trials, and the selections were communicated to the ICRISAT breeder, who is planning to multiply seeds by sib-mating.

BIG Haussmann with IER, INERA, INRAN, ISRA and LCRI

Seed of at least 10 preferred new sorghum materials multiplied and supplied to at least 3 partners annually (2007-11)
The Nigerian germplasm evaluation, as well as the evaluations of early generation breeding materials on-farm by farmers and on-station evaluations served as opportunity for selections by partners through direct visual evaluations. The diffusion of analysed data will further serve to create demand by other researchers during the comings season.

HFW Rattunde and E Weltzien

Output target 3A2: Heterotic patterns in WCA pearl millet and sorghum germplasm understood.

A set of factorial crosses among a total of 20 pearl millet landraces from the five WCA countries was evaluated by all the contributors at 7 locations during the rainy season of 2006, enhancing everyone's access and insights into useful variability and potentially promising combinations of different types of pearl millet landraces from WCA. The first evaluation of a set of diallel crosses among contrasting pearl millet germplasm groups has been initiated during the ongoing off-season. Genotyping of representative sets of pearl millet and sorghum germplasm has started in collaboration with the BECA in Nairobi, Kenya.

For the first time in 2005 and again in 2006 all interested partners in the different WCA countries have been able to test a range of the new guinea race sorghum hybrids. Results confirm consistently high levels of heterosis, especially for the Sudanian zone. Specific parents with high combining ability are starting to be become apparent, as well some patterns for high heterosis for grain productivity.

More detailed testing of grain yield heterosis is well underway, with the second season of data presently being analysed. In addition, 5 new guinea race hybrids and a local guinea race control, CSM 335, are being evaluated at 3 plant densities (67, 133 and 200,000 plants/ha) to confirm the results of yield potentials and grain yield components obtained in 2005. A sufficiently high rate of mineral fertilizers was applied to assess biomass and grain yield potentials of these hybrids.

The development of new hybrid parents of guinea race sorghum is advancing as planned. Thirteen new lines of diverse backgrounds and grain yield components have reached the BC6 stage of transfer into the male-sterility inducing cytoplasm. Seed of the lines developed earlier have been multiplied, and been made available to partners on request. For pearl millet a set of inbred lines representing the entire range of diversity from WCA is under development to initiate the process of parental line development parallel to the identification of heterotic groupings.

Activity 3A2.1: Multi-location evaluation of 100 pearl millet factorial crosses and their parental populations at 6 locations across WCA to study the effect of geographic and/or morphological distances of the parental populations on heterosis in pearl millet population crosses.

Milestones: At least 2 superior population crosses per partner country and agro-ecological zone identified and entering participatory recurrent selection programs (2007)

Field trials of a factorial design crossing involving 20 different parental populations from the five countries were evaluated at 7 locations (1 Senegal, 2 Mali, 1 Burkina Faso, 2 Niger, 1 Nigeria) during the RS 2006; and data entry and analysis are underway. Farmer and breeders performed visual selections that will enter into the overall analysis.

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Published article on combining ability patterns of WCA pearl millet landraces (2008)
The data from above trials will serve as a basis for this publication.

BIG Haussmann

Activity 3A2.2: SSR Genotyping of 250 pearl millet and 210 sorghum accessions for heterotic grouping

Milestone: Results on use of markers for assessing heterotic groups published (2008)

The sorghum and pearl millet accessions were selected from the germplasm collections evaluated for use in WCA, and for sorghum, including accessions and varieties in use in current hybrid breeding. Seed of selected accessions was sent for marker analysis.

BIG Haussmann and HFW Rattunde
with University of Hohenheim

Activity 3A2.4: Heterosis in Guinea-race sorghum hybrids assessed

Milestone: 2006: Regional Hybrid trials provided to WCA collaborators

A total of 91 experimental sorghum hybrids (based Guinea or inter-racial A lines crossed with Guinea male-parents) were produced and distributed as observation nurseries in 2006 for evaluating fertility restoration and agronomic desirability of hybrids *per se* and relative to the adjacent male-parent. These nurseries were provided to IER-Sotuba and INERA-Saria.

Regional Hybrid trials for collaborative yield testing of hybrids were prepared and dispatched to Mali, Burkina Faso, Senegal, and Nigeria (Table 1). Trials consist of 7 to 13 hybrids, based on adaptation zone and seed availability.

Table 1. Regional Hyrid Trials 2006

Zone	**N. Sudanian**		**S. Sudanian**					**Guinean**
Site (Country)	Bambey (Senegal)	Saria (Burkina Faso)	Bengou (Niger)	Samanko 1st Date (Mali)	Samanko 2nd Date (Mali)	Sotuba, Cinzana (Mali)	Sinthiou (Senegal)	Samaru (Nigeria)
# Entries	12	12	16	18	55	55	16	18

The Regional Sorghum Hybrid Trials in 2005 were conducted with NARS collaborators in the Northern Sudanian zone (ISRA, Bambey, Senegal; INERA, Saria Burkina Faso), the Southern Sudanian zone (INRAN, Bengou Niger; ISRA, Sinthiou Senegal; IER-Sotuba, Mali; and ICRISAT-Samanko, Mali (at two dates of sowing)), and the Northern Guinea zone (IAR-Samaru, Nigeria).

All trials had significant genetic differences for grain yields, with acceptable heritabilities and standard errors (Table 2). The grain yield superiority of hybrids over the local check is significant in the Southern Sudanian zone, with the best hybrid producing at least double the yield of the local check variety. The mean yield of all hybrids tested showed a 17 to 58% superiority over the local check, equivalent to 0.3 to 0.9 t more yield. In contrast, the superiority of these hybrids in the Northern Sudanian and Guinean zones were considerably less, indicating the need to develop other hybrids for these regions.

Table 2. Mean grain yields (t/ha) of all hybrids, best hybrid, open pollinated variety and local check variety in Collaborative Sorghum Hybrid Trials in the Northern Sudan (2) Southern Sudan (5) and Guinean (1) zones 2005

Zone	**N. Sudanian**		**S. Sudanian**					**Guinean**
Location	Bambey Senegal	Saria Burkina Faso	Bengou Niger	Samanko 1st Date Mali	Samanko 2nd Date Mali	Sotuba Mali	Sinthiou Senegal	Samaru Nigeria
Yield Best Hybrid	1.86	2.93	3.70	3.69	3.11	3.55	2.73	1.88
Mean (all Hybrids)	1.09	1.50	2.03	2.66	2.00	1.97	1.98	1.55
Best Variety	1.83	1.94	2.64	3.30	2.46	2.00	1.91	1.92
Mean (all Varieties)	1.15	1.12	1.45	1.81	1.59	1.21	1.21	1.20
Local Check	93B1062	Local 1	Sinthiou Local	CSM 388	CSM 388	CSM 388	Guinea Local	Fara Fara 27
Yield Local Check	1.48	1.75	1.73	1.79	1.58	1.25	1.37	1.92
Stand. Error	0.25	0.28	0.30	0.27	0.27	0.30	0.16	0.26
Heritability	0.79	0.77	0.85	0.87	0.83	0.87	0.93	0.63

HFW Rattunde, E Weltzien with IER, IAR, INERA, ISRA

Examination of the five highest yielding hybrids in each trial reveals the prevalence (and thus high combining ability) of a few male parents. Late maturing male parents from Humid West Africa; Nigeria (Fara Fara and IS 7978) and Cameroon (IS 30804 and IS 15629) occurred very frequently in the top yielding hybrids. The commercial feasibility of these hybrids is still unclear until off-season seed production techniques can be perfected. A male parent of the bicolor race (CSM 52-114) also consistently produced high yielding hybrids, although the tighter glumes make threshing difficult. The potential of inter-racial hybrids was exhibited in Samanko late-sown environment. However, due to seed limitations, these hybrids were not tested in other environments and their response across variable sowing dates still needs to be assessed.

Results of multi-location guinea race sorghum heterosis trials analysed (2007)
Sets of hybrids made on a wide range of new guinea race A-lines, representing West, Central, and North-, as well South-Eastern African origins with a wide rage of restorer lines from WCA were evaluated at 4 locations during 2005 and 2006. Data analysis is underway, and shall results in a PhD thesis.

S Dagnoko, HFW Rattunde with IER, INRAN

Activity 3A2.5: Physiological characterization of heterosis in Guinea-race hybrids

Milestones: The contribution of individual sorghum yield components and panicle traits to grain yield heterosis quantified (2008)

As part of the heterosis trials mentioned above a wide range of panicle traits have been assessed. These assessments will be used to gain insights into the role of specific yield components for increasing grain yield in superior hybrids.

S Dagnoko, HFW Rattunde, B Clerget, E Weltzien with IER, INRAN

Adaptation of first generation guinea hybrids to different agronomic conditions assessed (2008)
Five superior hybrids were tested at three different stand densities and higher fertility, to test whether the yield potential of these materials is higher than that of parental varieties.

B Clerget and HFW Rattunde

Output target 3A3: Sorghum and pearl hybrid parents made available to NARS

Activity 3A3.1: Develop diversified Guinea-race sorghum maintainer and restorer lines

Milestones: Ten A/B pairs of diverse Guinea Landrace varieties advanced to BC5 generation (2006)

A diverse set of Guinea landrace maintainer lines were identified from the Guinea-race Core Collection, which samples the 3,900 Guinea-race accessions in the ICRISAT World Sorghum collection. A total of 13 maintainer lines were sterilized to produce A/B pairs. The maintainer lines were crossed to CK60A, and subsequently backcrossed to the recurrent parent, with the BC4 generation completed in the 2005/2006 off-season and the BC5 generation being completed in the 2006 rainy season (Table 3). These 13 A/B pairs extend the diversity of landrace-based Guinea-race A-lines beyond the initial three A-lines (Fambe A, IPS0001 A, and CSM 219A, all of Malian origin) previously developed, both for geographical origin, grain size and maturity. All of these A lines, being based on landrace germplasm, are of tall height.

A dwarf, photoperiod sensitive Guinea-race A-line (GPN 271-20 A) was produced from a derivative of the random-mating Dwarf Guinea Population. This population derivative also contains the A1 cytoplasm, from CK60A. This is truly dwarf, with short internodes and photoperiod sensitive, flowering at the beginning of October with late June sowing date. This A-line was multiplied in isolation in 2006.

Table 3. Genotypes and number of BC4 lines and corresponding B lines sown 2006 per recurrent parent and backcrossed to BC5

Landrace Parent	Snowden race	Origin	No. of Lines
IS 27580A/B	guiniense	Burkina Faso	7
IS 6749A/B	guiniense	Burkina Faso	5
IS 6781A/B	guiniense	Burkina Faso	5
IS IS27494A/B	gambicum	Burkina Faso	4
IS 19970A/B	guiniense	Senegal	7
IS 20064A/B	margaritiferum	Senegal	4
IS 20114A/B	gambicum	Senegal	2
IS 22677A/B	guiniense	Mali	16

Landrace Parent	Snowden race	Origin	No. of Lines
IS 23645A/B	margaritiferum	Gambia	3
IS 27013A/B	durra-caudatum	Sudan	3
IS 3534A/B	conspicuum	Sudan	5
IS 9220A/B	margaritiferum	Uganda	3
IS 14414A/B	conspicuum	Malawi	3

HFW Rattunde and E Weltzien

WCA partners trained in breeding techniques for creating Guinea-race sorghum hybrids adapted to WCA (2007)

The training course (to be held in 2007) will address the specific need to train sorghum breeder and their technicians in methods necessary for successful hybrid breeding, as well as the specificities of working with photoperiod-sensitive materials of the guinea race.

HFW Rattunde, E Weltzien, B Clerget with ROCAR*S*

At least 2 diversified guinea-race maintainer and restorer lines shared with at least three NARS in WCA (2008-11)

NARS have started to request hybrid parents for guinea races sorghums. Seed of FambeA and/or IS3534A was sent to Nigeria, Niger, Burkina Faso and Mali for initiating production of experimental hybrids. The training course may increase this trend.

HFW Rattunde and E Weltzien

Activity 3A3.2: Development of pearl millet inbred lines in West African background, and test of their general combining ability (GCA)

Milestones: At least 2 new pearl millet inbred lines with good GCA available to NARS/year (2009-2011)

We evaluated 432 testcrosses between WCA pearl millet landraces and 3 different male sterile lines at Sadore in RS 2006, to characterize fertility restoration/maintenance and to gain preliminary information about general combining ability. Data entry and analysis is underway. Lines are being developed out of the WCA pearl millet landraces and improved cultivars, these materials are currently at an inbreeding stage between S2 and S4 (depending on when inbreeding was started). A total number of 411 lines is currently under development.

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Output 3B. Improved breeding populations and open-pollinated varieties of groundnut, sorghum and pearl millet with adaptive advantages and/or improved yields under defined environmental and management conditions (including resistance to *Striga*) developed annually and made available to partners through regionally coordinated, largely participatory breeding efforts, integrated with natural resource management research, to meet the needs of poor farmers in each of the major agro-ecological zones of WCA

MTP Output Targets 2006

Partners from 4 countries trained in tools for participatory recurrent selection

700 F2-F7 groundnut breeding populations and lines screened for enhanced multiple disease resistance including rosette virus

While we expect hybrid breeding to open new perspectives for cereal improvement and seed system development for West-Africa, breeding open-pollinated varieties of sorghum and pearl millet will continue, and will be increasingly integrated with the hybrid breeding efforts. Breeding groundnut varieties for the needs of poor farmers, specifically women farmers shall continue.

The variety breeding and general crop improvement efforts are increasingly targeting specific needs of farmers. Thus the crop improvement efforts are addressing specific agro-ecological zones in WCA, as well as the evolving needs of intensifying production systems. Increasing the specificity of our plant breeding and variety development efforts is possible only through a close partnership with national researchers in the region, as well as farmers, farmer organizations, and development projects targeting rural area development. We are placing high emphasis on the development and application of participatory breeding tools to improve the effectiveness and efficiency of achieving outcomes for farmers in WCA.

Improving grain yield in specific WCA growing and production conditions is of particular concern, specifically for pearl millet and sorghum, which have very high biomass yields, good adaptation to climate variability and change, and are relatively well protected against the common diseases and pests. Efforts to increase *Striga* resistance in farmer preferred cultivars are being pursued, as well as options tested to integrate *Striga* control options successfully. Searching for options of increasing the partitioning of photosynthate to high quality grains is thus necessary for WCA.

Nutrition and health concerns as targets for crop improvement research in WCA are gaining importance, and breakthroughs are being achieved. New groundnut varieties can resist the early invasion by the aflatoxin producing fungi (*Aspergillus flavus*). Combined with improved post-harvest techniques farmers now have the option to grow groundnuts that will not have negative health effects on those who consume them. Tools for monitoring the contamination of harvested or processed products are now available, and could be used for consumer protection.

Output target 3B1: Availability of pearl millet and sorghum cultivars with high and stable mineral (Fe, Zn) content in whole and decorticated grain

With the addition of a nutritionist to our team, our chances to effectively address micro-nutrient nutrition through crop improvement innovations have been significantly improved. We have been able to augment reliable information and research results on causes for mal-nutrition of young children and their mothers in regions that depend on sorghum and pearl millet as their staples. We are thus contributing to in-depth baseline studies of mineral mal-nutrition in targeted project areas.

For the short term, we have targeted to quantify losses of mineral content, and possibly changes in availability during key stages of processing, which have not received much research attention to date. Testing of varietal differences for these key traits require methodology development, which has been launched in recent years. The methods will include women farmers involved in processing whenever appropriate in a participatory manner.

To study genetic variation and environmental stability of mineral contents in improved cereal cultivars and landraces with contrasting grain characteristics, replicated experiments involving 40-60 pearl millet and sorghum cultivars from the WCA region, were conducted in both 2005 and 2006 in Niger and Mali. The results from 2005 revealed highly significant differences between the entries and estimates of heritability on a plot basis of 61% for Fe and 83% for Zn contents in the whole grain. The fertilizer treatments did not have any effect on the grain mineral contents. Methods for better quantifying and possibly predicting decortication losses are presently being tested.

Activity 3B1.1: Screening diverse pearl millet and sorghum cultivars for mineral (Fe, Zn) content of the grains, determine environmental stability and decortication losses

Milestones: Report on and seed of contrasting pearl millet varieties for Fe & Zn content available for distribution (2007)

Experiments involving 40 pearl millet cultivars (with two fertilization levels and 3 replications) were conducted in both 2005 and 2006 at Sadore, Niger, to study genetic variation and environmental stability of mineral contents in improved pearl millet cultivars and landraces with contrasting grain characteristics. The results from 2005 revealed highly significant differences between the entries and estimates of heritability on a plot basis of 61% for Fe and 83% for Zn contents in the whole grain. The fertilizer treatments did not have any effect on the grain mineral contents. Grain analyses of the 2006 trial are underway.

BIG Haussmann

Report and seed of contrasting sorghum varieties for Fe & Zn content available for distribution (2007)
Experiments involving 90 and 70 sorghum varieties of different origins and backgrounds were evaluated for Fe&Zn contents during 2005 and 2006, respectively. The trials are also being used to study relationships between ease of

decortication, other physical grain characteristics and the degree and amount of Fe and Zn losses in processed grain, and possibly foods.

HFW Rattunde, M Smit, E Weltzien with IER and HKI

Activity 3.B1.2 Assess opportunities for enhancing human nutrition in sorghum and pearl millet based cropping systems in WCA

Key sources of variation for micronutrient densities in sorghum and pearl millet identified (2006)
To identify sorghum varieties with high grain iron and/or zinc contents, a set of 90 sorghum varieties adapted to the Sudanian and Guinean-zones of West Africa were evaluated. The varieties tested included landrace varieties from Mali and Burkina Faso, accessions from the Guinea-race Core Collection of world-wide origins, and breeding lines and varieties from ICRISAT and Institut d'Economie Rural (IER) programs in Mali. Three replicate field trials were conducted on both red (P3b) and black soil (CSd) fields at ICRISAT-Mali in 2005. Although the early end of the rains resulted in severe drought stress in the black soil field, with later maturing entries producing no grain, acceptable yields were obtained from the red-soil environment.

Selfed, decorticated grain from each plot of the red-soil environment were analysed for iron and zinc contents at ICRISAT-India. Decorticated grain was analysed since previous analyses showed decortication reduces contamination, and, as most grain in West Africa is decorticated for food preparation, it corresponds most closely with the consumed product. Additional grain characteristics were observed such as pericarp thickness, decortication yield (10g samples in triplicate in TADD for 3minutes), ease of decortication (visual observation of extent of decortication with TADD) were also observed.

Varieties showed highly significant variation for iron and zinc contents of decorticated grains (Table 4). The varieties with the highest iron and zinc contents surpassed the mean by 19%, and 31%, respectively. The entry-mean heritability estimates for iron and zinc are above 0.70, indicating that genetically superior varieties can be bred. The superiority of these varieties needs to be confirmed however through testing in additional environments.

All of the grain characteristics studied showed highly significant genetic variation, with large genotypic ranges and high estimates of heritability. However, most of these characteristics showed no correlation with iron or zinc contents of the decorticated grain. Only decortication yield showed a moderate positive relationship with iron (r=0.52) and zinc (r=0.58). The high correlation between iron and zinc contents (r=0.84) suggests that the more highly heritable zinc content may be used for preliminary, indirect selection for iron contents.

Table 4. Mean, range, standard errors and entry-mean heritability estimates for 90 Sorghum varieties tested in Mali, 2005

Trait	Units	Mean	Minimum	Maximum	Std Err	Heritability
Iron	ppm	25.2	19.7	30.0	1.56	0.72
Zinc	ppm	15.7	10.5	20.6	1.20	0.80
Pericarp Thickness	Score 0(thin)-1(thick)	0.2	0.0	0.8	0.08	0.89
Ease of Decortication	Score 1(easy)-5(most difficult)	1.9	1.0	4.4	0.22	0.91
Decortication Yield	%	81.6	63.9	88.2	2.30	0.81
Vitreousness	Score 1(floury) to 9(vitreous)	3.4	1.6	6.7	0.31	0.90
Seed Weight	g per 100 seeds	2.4	1.4	3.4	0.11	0.92

HFW Rattunde, EWeltzien and M Smit

Literature review and survey published on importance of sorghum and pearl millet in West-African diets, with specific reference to micronutrient nutrition (2008).
An internal report and literature review was completed and is being shared with partners before finalizing for a publication. It is entitled: 'Evaluation of bio-fortification strategies and introduction of the best means to enhance the diets of nutritionally disadvantaged populations in developing countries.'

To help guide ICRISAT and West-African NARS partners to appropriately include nutritional enhancement in ongoing sorghum and millet variety development activities, a thorough review of literature was conducted. This review compiled and synthesized the information for Mali, Niger and Burkina Faso on millet and sorghum consumption, their contribution to overall diet and nutritional role, with special emphasis on micronutrients (iron and zinc).

In Mali 85% children (6 to 59 months age) suffer from anaemia, 92% in Burkina Faso and the figures for Niger, although not available, can not be any better. The deficiency of iron and zinc results in weak immune systems, reduces growth and cognitive development, thus contributing to the alarming child mortality rates of around 25% as well as restricting the potential of many of those who survive.

Micronutrient deficiencies may also be serious in adults as well, especially women. High rates of anaemia in pregnant women in Burkina Faso (68%) and Mali (63%) may place women's lives at risk during childbirth.

Millet and sorghum are confirmed to be the staple foods in the three countries, although rice is also important along the Niger river in Mali. In Niger millet (70%) and sorghum (20%) account for 90% of total cereal consumption. Their contributions, together with some maize, are similar in Burkina Faso (90%) and Mali (75%). These cereals have tremendous dietary importance, as diets are primarily based on plant-derived products with relatively little animal products. Sorghum and pearl millet contribute 67% to 90% to the total consumed energy (kilo calories). Millet and sorghum are rich sources of the micronutrients iron and zinc and of B-vitamins. Calculations based on mean iron and zinc levels from ICRISAT trials (pearl millet at Sadore, sorghum at Samanko) suggest that these cereals provide 29-51% of iron and zinc required by children, the group suffering most serious levels of micronutrient deficiencies and whose diets are based predominantly on millet and sorghum.

The review concludes that there needs to be both a) increase of bio-availability of existing sources of micronutrients through better transformation and food preparation practices, including the combination with other foods to increase absorption of iron and zinc, and b) exploiting the genetic diversity for iron and zinc contents in the staple cereals.

Marjolein Smit, H Fred W Rattunde and Eva Weltzien

Output target 3B2: Availability of genetically broad-based pearl millet and sorghum gene pools

To use the enormous variability among pearl millet and sorghum accessions from the WCA region for effective, and sustainable varietal improvement we have started to develop broad based populations. These populations tend to be well adapted to specific zones of adaptations, and harbour genetic variability for key traits targeted for improvement. Some examples are: the development of a pearl millet population combining available sources of *Striga* resistance, the guinea race sorghum population with reduced height due to reduced internode length, and thus improved stover digestibility.

Activity 3B2.1: Population diversification and recurrent selection for farmer-preferred traits including *Striga hermonthica* resistance in pearl millet

Milestone: At least three broad-based pearl millet populations developed and seed available for specific agro-ecologies of WCA and available for distribution (2008)

Farmer-preferred parental materials for the diversified populations are being identified from the 2006 rainy season trials (both on-station and on-farm) in Senegal, Mali, Burkina Faso, Niger and Nigeria. These will be crossed and recombined in the off-season and rainy season 2007, to be made available in 2008.

BIG Haussmann

One highly diversified pearl millet genepool with improved resistance to *Striga hermonthica* developed for use in West African breeding programs (2009)

A first screening of 64 pearl millet landraces from Niger was conducted in RS 2005 at Sadore under artificial striga infestation. Out of the least sensitive populations, both S1 and Full-sib families were developed in the off-season 2005-06. These were then evaluated in artificially infested field trials at Sadore, and partially also in two on-farm trials at Toroid and Falwel (both Niger) in the RS 2006. Data are being compiled.

BIG Haussmann

Activity 3B2.2: Creation of diversified Dwarf Guinea Sorghum Populations

Milestones: Partners from 4 WCA countries trained in tools for participatory recurrent selection (2006)

A training course involving pearl millet breeders and sorghum breeders, their technicians, and partners from farmer organizations as well as development agents from large-scale development projects from Mali, Burkina Faso, Niger and Nigeria was conducted from 9-18 September 2006 in Segou, Mali. In addition to the plant breeders the course participants include plant breeding technicians, farmers chosen from farmer organizations active in seed and variety identification activities, and development workers involved in activities related to variety testing and seed production. The course covered three main topics: a) an introduction to recurrent selection methods and factors that contribute to successful selection gains; b) Options for farmer participation in the different stages of a recurrent selection program for variety development and c) Organizational and institutional issues to consider in setting up and implementing participatory variety development programs. The last day of the workshop was used to plan activities for future collaboration on sorghum and pearl millet breeding.

E Weltzien

One diversified dwarf Guinea – race Sorghum population with farmer preferred traits available for at least two different agro-ecologies of WCA (2009)

One trait that attracts farmers' attention and strong expressions of preference is the stover quality of guinea race sorghums. Diversifying and improving these locally well adapted sorghums for stover quality may contribute significantly towards improving the economic value of the sorghum crop in WCA. We thus characterized key parameters for stover quality in novel dwarf- and landrace-sorghum varieties adapted to WCA and their relationship with agronomic traits.

Assessment of stover quality parameters of stem samples from 70 novel dwarf-stature Guinea-race sorghum lines and landrace check varieties was conducted to a) quantify the genetic variability for stover quality provided by our new dwarf Guinea-race sorghums, and b) assess relationships between stover quality and major agronomic traits. This first systematic assessment of stover quality of these materials will provide guidance on the opportunities and directions for developing novel dual-purpose sorghum varieties for West Africa.

The stem samples and agronomic measurements were made at ICRISAT-Samanko in 2004, in a four replicate trial. Key agronomic characteristics such as grain yield, maturity, stem length (distance from ground to base of peduncle), stem diameter, and internode lengths were measured. Stem quality parameters were estimated for dried, ground (1mm sieve) stem samples using NIRS at CIRAD, Montpellier. The parameters estimated were total minerals (MM), crude protein (CP), crude fiber (CBW), Neutral detergent fiber (NDF), Acid Detergent Fibre (ADF), Acid Detergent Lignin (ADL), In-vitro digestibility of dry-matter (IVD-DM) and In-vitro digestibility of organic matter (IVD-OM).

Highly significant genetic variation was observed for all quality parameters.

Considerable similarity among sister lines, and considerable differences between families of progenies and high entry-mean heritability estimates confirms the importance and repeatability of genetic differences for all quality traits (Table 5).

Table 5. Variation and entry-mean heritability for key stem-quality and agronomic traits among 70 new dwarf Guinea-race sorghum breeding lines and landrace checks

Trait	Units	Minimum	Maximum	Mean	Standard Error	Heritability
In vitro Organic Matter Digestibility	%	16	45	28	2.3	0.89
In vitro Dry Matter Digestibility	%	17	48	32	2.3	0.89
Acid Detergent Fiber	%	35	52	44	1.6	0.87
Neutral Detergent Fiber	%	60	86	76	2.2	0.88
Crude Fiber	%	33	50	42	1.5	0.89
Acid Detergent Lignin	%	5.0	8.6	6.8	0.3	0.91
Crude Protein	%	1.0	4.6	2.6	0.3	0.82
Total Minerals	%	2.1	6.4	3.9	0.6	0.63

Trait	Units	Minimum	Maximum	Mean	Standard Error	Heritability
Stem Diameter	Cm	1.4	2.5	1.9	0.1	0.71
Stem Internode Length Observed	Cm	4.5	23.8	12.1	0.8	0.97
Stem Length	Cm	65	252	137	8.9	0.95
Leaf Percent	%	26	58	41	2.2	0.88
Heading date	joulian d	260	287	275	1.5	0.92
Grain yield	g m2	22	249	129	23.0	0.74
Harvest Index	%	13	43	28	2.3	0.88

Shorter stem internode length was correlated with higher stem organic-matter digestibility (r= -0.64), indicating that approximately 40% of variation for stem digestibility due simply to stem internode lengths. Entries with very short internode (<12cm) show on average considerably higher nutritional values. Breeding lines with internodes less than 12cm, derived both from inter-racial pedigree breeding and from a Dwarf Guinea Population, showed higher organic-matter digestibility (adjusted by covariance for grain yield differences) and crude protein and lower NDF, ADF, and ADL mean values (Table 6). The 40 progenies with length of stem internode of less than 12cm had mean IVD-OM of 32.1, with a range from 20.1 to 44.8, as compared to traditional landrace varieties with IVD-OM ranging from 17 to 26. Also, short internode length showed strong association with higher leaf percent (r=-0.80).

Table 6. Mean stover quality parameters for Inter-racial and Dwarf Guinea lines with stem internodes 12cm or less as compared with landrace varieties

	IVD-OM	IVD-DM	ADF	ADL	NDF	CBW	CP	MM
Inter-racial	29	34	42	6.0	73	40	2.8	4.3
Dwarf Guinea	31	36	42	6.3	72	40	3.0	3.8
Landrace Varieties	*26*	29	47	7.2	78	45	1.8	2.7

Varieties with short stem internodes, however, do not necessarily exhibit higher stover quality. Certain varieties with intermediate to short stem internodes showed stem IVD-OM values that were no better than those of traditional landrace varieties (Table 7).

Table 7. Stem organic-matter digestibility, yield and internode lengths of dwarf- and traditional landrace varieties of sorghum.

Variety	IVD-OM	Grain Yield t/ha	Internode (cm)
Short Internode varieties			
01-CZ-F5P-169	35	0.3	13
GPN01 266-1-2	34	1.1	8
Grinkan	31	1.4	8
Nafalen	31	1.5	13
Malisor 92-1	26	0.6	8
CGM 19/9-1-1	21	1.5	15
Weli	20	1.8	14
Mean 40 varieties internodes<12cm	32	1.2	9
Landrace Varieties			
Bobodje	34	0.6	17
Sakoykaba	26	1.3	21
CSM 335	25	1.4	20
CSM388	19	1.5	24

Very strong correlations (r= –0.98 to –0.99) were observed between digestibility estimates (IVD-OM, IVD-DM) with NDF and CBW; indicating that these estimates are not independent and do not need to be examined separately.

The relationship of IVD-OM with grain yield was weak (r= -0.44), with combination of higher yield and digestibility being possible. Surprisingly, high stem digestibility was association with later flowering (r=0.78) (all average to late heading (270-285 days) entries had IVD-OM >30%). This may be due in part to later flowering being associated with lower harvest index (r=-0.74), and low harvest index being associated with higher digestibility (r=-0.62).

The major conclusions that can be drawn from these results are 1) new dual-purpose sorghum varieties with substantially superior stover quality and acceptable grain yield can be developed for West Africa, 2) the dwarf (short stem internode) phenotype is associated with improved stover quality, although considerable variation for quality exists within dwarf phenotypes and thus, 3) *in vitro* and/or *in vivo* assessment of stover quality of promising varieties are necessary to develop superior dual-purpose types that maximize total productivity and value of the crop/livestock systems.

HFW Rattunde, Eva Weltzien and D Bastinell*i*

Activity 3B2.4: Develop farmer preferred *Striga* resistant varieties of sorghum and options for integrated *Striga* management.

Milestone: Transfer of Striga resistance QTL's into at least on guinea race variety adapted to the Sudanian zone of WCA (2009)

BC2F1 were developed at IER, and are presently being analysed for specific markers for positive selection for he presence of he desired QTL's as well as for background selection for the target genotype.

D Kiambi with IER, BeCA

Approach tested for adapting integrated *Striga* control options to specific cropping systems in collaboration with farmers (2008)

A farmer field school methodology was adapted to work with pearl millet farmers on integrated *Striga* management options in Sahelian cropping systems. The approach was tested in two clusters of 6 villages each. Results indicate that the chosen combination of treatments resulted in a reduction of the amount of *Striga* seed in the soil.

T van Mourik and E Weltzien

Quantification of interaction between different *Striga* management options on *Striga* seed bank dynamics in the soil (2008)

In both sorghum and pearl millet systems the factorial combinations of three control options, varietal resistance, intercropping, and organic amendments were evaluated in on-station trials at Samanko and Sadore.

T van Mourik, E Weltzien and BIG Haussmann

Output target 3B3: New farmer-preferred pearl millet and sorghum cultivars with improved yields

The development of superior finished varieties is necessary in WCA, because many national programs have poorly supported breeding programs. They are also necessary as a proof of concept in this region, where farmer managed yield improvements have been rarely manifested for newly developed varieties of local dryland cereals. For pearl millet our efforts at variety improvement have re-started this year in several target production systems across the WCA region.

New guinea race sorghum varieties (tall and dwarf) are showing consistent yield improvements in farmer manage trails, primarily in the Soudanian zone. We have initiated efforts to increasingly target the southern Sahelian zone, as well as the northern Guinean zone.

An initial effort at mapping the adaptation of specific guinea race sorghum varieties, based on their photoperiod response, and thus time of maturation, has resulted in products that give some broad indications, but lend themselves to explaining issues of varietal adaptation to those involved in developing seed sector innovations, regionalizing seed policies, and preparing for seed distribution or commercialization.

Activity 3B3.1: Farmer-participatory recurrent selection for head/grain yield in diversified pearl millet populations

Milestones: Four improved, farmer-preferred pearl millet OPVs available to farmers in Niger and Mali (2009)

Farmers conducted full-sib progeny trials in population crosses at three locations in northern Nigeria, targeting the Sahelian zone. Farmers made visual selections, and researcher conducted agronomic evaluations. Joint selections are being recombined for further recurrent selection.

BIG Haussmann and S Boureima

Activity 3B3.2: Farmer-participatory sorghum variety development and testing

Milestones: Farmer preferred varieties from on-going trials registered in Malian Variety catalog (2007)

A set of 15 tall guinea race lines and varieties, and 15 short line and varieties were evaluated during 2005 and 2006 in multi-location yield trials in two areas of Mali, in the Sudanian zone. The trials were conducted at two research stations, and in 10 villages in 2005, and 9 villages in 2006. The varieties were assessed by researchers for agronomic performance traits (grain yield, panicle yield, panicle number, and 1000 grain mass). 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. After harvest, and analysis of the agronomic and preference data, farmers and researchers selected together the four best entries in each village. These four varieties were evaluated for their processing characteristics for local dishes, as well as for culinary traits of the main dish commonly prepared from sorghum in this region. The data is presently being analyzed for preparing release proposals, and other publications.

E Weltzien, HFW Rattunde, with IER, ULPC and AOPP

Tools for farmer participatory early generation testing of sorghum genotypes published (2008)

Specific tools for facilitating farmers' input into the evaluation and selection of sorghum varieties under testing have been tested over the past years in Mali. During 2006 these tools were disseminated through a training program for breeders. The tools are now being used in four countries in West-Africa. Based on feed-back from these users a publication shall be prepared.

E Weltzien, HFW Rattunde with IER

Activity 3B3.3: Information on variety adaptation made widely available

Milestones: Regional validation of the variety adaptation maps reported with the breeders of WCA countries (2008)

In collaboration with Agryhmet and using the regional data sets of weather observations, and a simplified water balance model, the dates for the end and the beginning of the rainy season across different ecologies in West Africa were estimated. Based on these estimates, and the known dates of flowering of widely tested photoperiod sensitive sorghum and pearl millet varieties, zones of adaptation were proposed, and mapped. Further refinement of these maps is under discussion.

PCS Traore, B Clerget, BIG Haussmann, E Weltzien, HFW Rattunde with IER

Publication of results, based on field studies and modeling, on the effect of *Striga resistance* of the host crop varieties on the effectiveness of different combinations of *Striga* control techniques (2008)

Trials observing *Striga* seed bank dynamics were conducted during 2005 and 2006 at Samanko, and Sadore estimating factors contributing *Striga* both seed production as well loss of viable seed in the soil. The preparation of a PhD thesis is underway.

T van Mourik

Output target 3B4: Availability of allele-specific molecular markers for genes controlling photoperiod sensitivity of flowering time in pearl millet and sorghum

As photoperiod sensitivity is key for varietal adaptation of sorghum and pearl millet in WCA, we are investigating options for increasing our efficiency in handling this character in a breeding program through the application of molecular markers. Material for this research has largely been assembled, tools and methods are being finalized. Protocols for phenotyping are available now, but need to be published.

Activity 3B4.1: Phenotyping and genotyping sorghum and pearl millet lines and accessions

Milestones: Paper published on effect of photoperiod on growth and development of West-African sorghum and pearl millet varieties (2007)

The 24^{th} of the two year series of monthly sowings of 12 pearl millet varieties was completed in June 2006. An additional sowing has been done in November 2006 to compensate for the failure of the sowing of November 2004. A publication is under preparation combining the results from the sorghum observations, with these new pearl millet results.

B Clerget, HFW Rattunde, BIG Haussmann, E Weltzien and S Boureima

Output Target 3B5: Improving plant growth model for highly photoperiod-sensitive sorghum and pearl millet

Understanding the biology of photoperiod sensitivity, and modelling plant growth and development of photoperiod sensitive sorghum and pearl millet are instrumental for devising avenues for further improvements of productivity, as well as for predicting responses to existing and future climate variability. A key issue for predicting varietal adaptation is a better understanding of the relationships between latitude and photoperiod-sensitivity. Trials to arrive at a better understanding of this situation have put in place over a large range of latitudes in WCA and ESA.

Similarly crucial for the adaptation and stability of productivity of the local cereals is a better understanding of the relationship between root, shoot growth and grain yield potential of photoperiod sensitive varieties. Studies have been initiated but require confirmation across years with different rainfall regimes.

Activity 3B5.1: Study relationships between latitude and photoperiod-sensitivity in sorghum and pearl millet

Milestones: Multi-latitudinal trials from equator to temperate latitudes conducted, data assembled (2008)

Five sorghum and five pearl millet West African varieties have been sown in May, June and July 2006 at the CIRAD station, Lavalette, Montpellier, France (43° 37'N). Leaf appearance and panicle initiation have been recorded. An international experiment on the effect of the latitude on the photoperiod-sensitivity of sorghum has been planned. From December 2006 to December 2007, 10 sorghum varieties from West, East and South Africa, will be monthly sown in Kenya, Tanzania, Mozambique, Zimbabwe and Mali.

B Clerget and M Mgonja

Output target 3B6: Groundnut breeding lines with resistance to groundnut rosette disease, early and late leaf spots and aflatoxin contamination available for distribution

In groundnut genetic enhancement, there has been a shift in emphasis from single stress factor resistance to multiple stress factors resistance to ensure wide adaptability of newly developed genotypes in the semi-arid tropics. Our collaborators have access to early-generation breeding populations, advanced breeding populations, and near-finished genotypes to enrich and diversify their national programs. ICRISAT is continuing to make new segregating lines, and stable varieties available to NARS partners for testing and release. Most of this work is being conducted in a collaborative manner, and involves farmers in the variety evaluation phase. Variety releases for specific countries are imminent, and farmers are continuing to adopt the new varieties from the trials plots. Increasing the availability of breeder's seed is increasing the potential for adoption of these varieties.

Activity 3B6.1: Screening groundnut breeding populations for multiple resistances

Milestone: About 700 F2-F7 breeding populations and lines with enhanced resistance to groundnut rosette disease and aphids screened for resistance to early and late leaf spots at Samanko, Mali (2006)

Groundnut rosette is the most destructive disease of groundnut in sub-Saharan Africa. Improved rosette 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). The resistant genotypes will form a strong component of overall integrated disease management strategies along with cultural and biological management options. A total of 844 diverse breeding populations and advanced breeding lines were screened for early leaf spot, the most prevalent disease at Samanko (Table 8). Segregating populations were grown essentially for generation advance and further selection.

Table 8. Breeding populations and lines screened for early leaf spot (ELS), Samanko , 2006

Objective	Generation	No. entries	Source	Number resistant to ELS (score ≤ 5)
Rosette resistance and earliness	F3	70	WCA	14
Rosette resistance and earliness	F4	64	WCA	9
Aphid resistance and confectionery (Virginia)	F4	55	ESA	8
Aphid resistance x ELS resistance	F4	124	ESA	23
Aphid resistance x rosette virus resistance	F5	33	ESA	0
GRV resistance	F6	36	ESA	5
GRV and dormancy	F6	63	ESA	4
Aphid and GRV resistance	F6	49	ESA	0
Aphid resistance inheritance	F6	27	ESA	1
Aphid resistance backcrosses	F6	8	ESA	0
GRV inheritance- aphid x GRV	F6	5	ESA	0
Dormancy and rosette resistance	F6	27	ESA	0
Aphid and ELS resistance	F6	16	ESA	1
Aphid and ELS resistance	F7	92	ESA	7
Rosette resistance	F7	5	ESA	0
High oleic acid and rosette resistance	F7	21	ESA	0
Aphid and rust resistance	F7	22	ESA	1
Aphid inheritance	F7	127	ESA	2
Total		**844**		

Generation advance: We grew 70 F3 and 63 F4 bulk populations at Samanko for generation advance. These populations are derived from crosses involving early maturing susceptible lines and sources of resistance to groundnut rosette disease. The aim of screening these for early leaf spots is to eliminate the super susceptible ones. Among the F3 populations 14 recorded a score of ≤ 5 (on a scale of 1-9, where 1 is resistant and 9 highly susceptible) while 9 of the F4 populations were rated as resistant. The most susceptible population had a score of ≥ 7. Single pod bulks were made from the most productive plants with tolerance to ELS. These will be tested in rosette disease nursery at Samaru, Nigeria at an appropriate time.

Evaluation of diverse breeding lines for early leaf spot: Breeding lines derived from various population for incorporating resistance to both Groundnut Rosette Virus and aphid into different backgrounds were grown for seed increase and screened for early leaf spot. Selected lines based on pod load will be evaluated for yield and other desirable traits in initial variety trials in the 2007 crop season.

Advanced breeding nursery: At the request of the groundnut breeder at the Savanna Agricultural Research Institute, Tamale Ghana, an observation nursery consisting of 12 rosette resistant early maturing (90 days) lines were dispatched. Breeder seed of these lines was produced at Samanko.

BR Ntare and AT Diallo

Breeder seed production: Breeder and foundation seed production is an essential component of the breeding program. Breeder seed (30-135 kg) of six promising early maturing and rosette resistant varieties were produced. In addition foundation seed of the currently popular varieties in Mali (ICG 7878, ICGV 86124, ICGV 86024, ICG (FDRS) 4, Fleur 11 and JL 24) was produced and quantities range from 225-450 Kg (Table 9). This seed will be sold to replenish the revolving fund established in 2005.

Table 9. Breeder and foundation seed production (kg) produced at Samanko, 2006

Variety	Breeder	Foundation
ICG 7878	-	102
ICG 6222	-	150
ICG(FDRS) 4	-	465
ICGV 86124	-	225
ICGV 86024	-	388
ICGV-IS 01836	65	
ICIAR 6 AT	135	
ICIAR 19 BT	-	165
ICIAR 7B	60	
ICGV-IS 01835	30	
JL 24	-	295
Fleur 11	-	378
ICGV 86124	15	
Fleur11	2	
ICGV 86024	12	
ICG 7878	2	
ICG 7	12	
JL 24	2	
ICG 6222	2	
ICGV-IS 01859	5	
ICIAR 19 BT	5	
ICGV 92093	2	
ICGV-IS 01851	3	
ICGV-IS 01850	4	
ICGV 97188	4	
ICIAR 6 AT	1	
ICG(FDRS)4	4	
ICIAR : Varieties jointly developed by ICRISAT and with IAR, Nigeria		

BR Ntare and AT Diallo

Activity 3B 6.2: Evaluating advanced breeding lines with multiple resistances for yield and other performance trait

Milestone: Two groundnut varieties released in Senegal and Mali (2006)

Farmers' access to improved groundnut varieties is fundamental to achieve the desired the impact. Farmers select varieties based on their own preference criteria for variety use and cultivation. This enhances the rate of adoption.

Participatory variety selection (PVS) trials were initiated in the main groundnut growing areas regions in Senegal (11 varieties) and Mali (13 varieties) in 2003. During the three-year testing farmers in Senegal selected ICGV 86124 and ICGV 89063, while in Mali they have selected ICGV 86124. These varieties also showed wide adaptation in earlier regional variety trials conducted across West Africa. Both varieties are early maturing and high yielding (2.0-2.5 t/ha under good management on-farm). In addition, ICGV 89063 is tolerant to Aflatoxin contamination while ICGV 86124 is tolerant to drought. Based on these attributes and farmers' preference they have been recommended for release, and the relevant documents have been submitted to the variety release committees in the two countries. Formal release has been delayed as none of the release committees in both countries has met to approve the varieties for registration.

BR Ntare, A Dasylva and O Kodio

Lines with combined resistance to groundnut rosette disease, aphids, early and late leaf spots evaluated for yield performance (2007)

During the 2006 crop season, a number of lines with desirable agronomic and quality characteristics (plant type, pod shape, seed size and color) will be entered into preliminary on station trials to evaluate their yield potential.

B Ntare

A report on groundnut participatory variety selection published (2007)

A draft synthesis report on the participatory variety selection (PVS) process was prepared, summarizing groundnut variety selection trials conducted in Mali, Niger, Nigeria and Senegal. It documents the pathways to adoption of improved groundnut varieties, the lessons learned and the perspectives for enhancing variety adoption. Surveys were initiated in Dec 2006 for additional information to strengthen the report.

B Ntare and J Ndjeunga

10-25 breeding lines with multiple resistance to groundnut rosette and foliar diseases made available on request to NARS in WCA (2008)

Promising lines from the preliminary evaluation trials will be made available to NARS on request.

B Ntare

Activity 3B6.3: Conduct adoption and impact assessment of groundnut improvement research in WCA

Survey on the adoption and impact of improved groundnut varieties in four countries of WCA completed (2008).

Surveys on the adoption of improved varieties in Mali, Niger and Nigeria were initiated in December 2006.

J Ndjeunga and B Ntare

Output 3C: Crop management, *Aspergillus flavus* resistant groundnut varieties and post-harvest technologies available to reduce aflatoxin contamination in food and feed products in the SAT of WCA

MTP Output Target 2006: Analysis of results from integrated aflatoxin management options trials undertaken

The main health related research area the WCA is pursuing concerns of aflatoxin contamination in groundnut. Aflatoxin is carcinogenic and have a broad range of negative side effects on the immune system and growth and development, especially of children. While it would be useful to understand the medical ramifications better, we focus on options to reduce contamination of food and feed products. The field research conducted with farmers confirms on-station results that aflatoxin contamination can be reduced significantly, down to levels that are safe for consumption for young children. Monitoring of marketed products also showed that quality of available products covers an enormous range, including samples that are safe for consumption. Producer and consumer awareness of the existing problem, as well as options for its improvement are extremely low, but we are starting to tackle them.

Output target 3C1: Post-harvest technologies, and resistant groundnut varieties tested with producers, and contamination levels monitored at the consumer end.

Research results from on-farm trails testing different options for reducing aflatoxin contamination in a range of locations are all very positive, and showing the feasibility of control options. These results need to be published, and undergo economic feasibility analysis.

Activity 3C 1.1. Develop breeding populations and lines with enhanced resistance to aflatoxin contamination

Milestones: A synthesis report on Integrated Aflatoxin management published (2007)

Data from verification and demonstration trials of technologies to minimize aflatoxin contamination were analyzed. Preparation of an information bulletin is in progress.

B Ntare and F Waliyar

At least 10 promising breeding lines resistant to foliar diseases and aflatoxin contamination available to NARS in WCA (2008)

Promising lines from the preliminary evaluation trials (see above) will be available for distribution to NARS on request.

B Ntare and F Waliyar

Activity 3.C.1.2 Test crop management options to reduce Aflatoxin contamination in groundnuts

Milestone: Technologies to minimize aflatoxin contamination scaled-out to 3 countries in WCA (2007)

On-farm demonstration of best-bet harvesting techniques and tolerant varieties: We have successfully developed and tested integrated management technologies to prevent aflatoxin contamination at the farmer level in Mali. However large scale dissemination of these technical packages, along with intensive sensitization campaigns across the commodity chain remains a major challenge. Awareness about aflatoxin contamination is improving and efforts were made to continue dissemination technology packages on the control of aflatoxin contamination at production level.

On-farm trials/demonstrations of the best-bet harvesting and drying techniques were conducted in Nigeria for a second year and in Senegal for the first time. In Nigeria, improved method of drying the pods facing the sun reduced Aflatoxin contamination by as high as 97% compared to the farmers' method of windrowing. Aflatoxin content in seed ranged from 3.73 to 9.00 ppb under the improved method compared to 6.00 to 337.00 ppb under the traditional method. These results are consistent with those obtained in the previous crop season. This simple management technique can significantly contribute to healthy groundnut products and needs to be promoted widely.

Raising awareness through training workshops and other information dissemination pathways: ICRISAT provided technical and partial financial support for a 2-day workshop on best-bet harvesting and drying techniques in Niger. Projet Intrants of FAO Niger organized the workshop. Two representatives from each of the four regions of Niger attended the workshop. These would in turn impart the knowledge to a large audience in their respective areas.

In Mali, a two-day workshop on crop management practices and quality control was held for a group of farmers in Sanakoroba district. KILABO, a local NGO facilitated the workshop. Two extension agents and 15 women attended. At the request of Women Association of Wakoro in Doila, ICRISAT organized a 4-day training workshop in crop management. During these workshops, the participants were sensitized on how to minimize the aflatoxin contaminataion.

Group discussions were regularly held with farmers, traders and processors to assess their awareness. The interaction revealed that many farmers were ignorant of the aflatoxin problem. They opined that since there is no visible indications of aflatoxin on the seed they considered end-of season drought to be responsible for low yields and bitterness of seeds. It is known that any delay in harvesting the crop under end-of season drought could severely reduce yield and increased aflatoxin contamination.

Information dissemination: Under the CFC supported project, information leaflets on how to minimize aflatoxin contamination (English and Hausa languages) were prepared in Nigeria and will be widely distributed. In Mali 1000 flyers (in Bambara and French) have been distributed to raise awareness about Aflatoxin contamination.

Information was also disseminated using posters. Two posters on integrated management of Aflatoxin and ICRISAT strategy to control Aflatoxin contamination were displayed at the Malian National Agricultural Research week. More than 500 persons including policy makers, NGOs, etc., visited the stand.

BR Ntare, AT Diallo, HY Bissala, F Waliyar,
C Echekwu and A Da Sylva

Monitoring aflatoxin contamination in target areas in WCA: In addition to on-farm trials/demonstrations, ICRISAT has also been monitoring levels of Aflatoxin contamination from 20 farmers in the districts of Kolokani, Kayes and Kita in Mali. Some of the farmers have participated in participatory variety trials while others have visited some of the demonstration plots in the districts. From 21 samples in Kolokani, the Aflatoxin content ranged from 0.2 to 75 ppb, in Kayes (20 samples) the range was 6.39 to 1597 ppb, and in Kita (80 samples) the range was 4.2 to 1152 ppb. The alarming high levels of Aflatoxin contamination in Kayes and Kita are of concern and show that these areas are Aflatoxin risk prone. However, results from Kolokani showed a significant decline in the level of aflatoxin contamination. This is an indication of adoption of improved management practices.

Aflatoxin contamination was also determined in samples from pods, kernels and groundnut butter in several markets in Bamako city. The samples showed a wide range of aflatoxin content levels (Table 10). Over 80% of the samples had Aflatoxin content far beyond permissible (i.e 20ppb) levels for animal feeds. Permissible level for human consumption is < 5 ppb. These high levels in market samples arise from contamination through transportation, poor handling and storage conditions. Thus stakeholder sensitization about measures to control contamination further down the commodity chain is essential.

Groundnut is an important component of the diet of many groundnut producers in West Africa. Many people are not only malnourished but also chronically exposed to high levels of toxic fungal metabolites (mycotoxins). Aflatoxin contaminates staple foods, in West Africa, particularly maize and groundnuts, as a result of hot, humid storage conditions that promote fungal growth. Groundnut paste is used in nearly every household in Mali. High exposure to aflatoxins occurs throughout childhood in the region suggesting that growth and development could be critically affected. It would thus be important to assess the exposure of aflatoxins in relation to anthropometric measures (weight, height, age, malnutrition scores, weaning status and the economic status of the mother and family etc) in children in the target areas. Linking with surveys on malaria or other health related issues (level of malnutrition, types of diet etc) in target villages to assess aflatoxin exposure is vital. Elsewhere in West Africa (Benin and Togo) a striking association between exposure to aflatoxin in children and both stunting (a reflection of chronic malnutrition) and being underweight (an indicator of acute malnutrition) has been revealed. This emphasizes the need to investigate this question and develop strategies to minimize exposure to mycotoxins in staple foods.

Table 10. Means and ranges for Aflatoxin content from groundnut market samples in Mali, 2006

Market/Product	No. of Samples	Mean (ppb)	Range (ppb)
Groundnut paste			
Kita	22	203	30-1674
Bamako	69	260	5-2914
Kernels			
Bakodjikoroni	22	103	3-914
Banakabougou	72	155	7-2666
Banconi	25	222	4-1150
Daudabougou	24	179	5-2040
Dibida	12	20	5-46
Magnambougou	10	92	2-455
Medine	83	135	3-1800
N'Golonina	16	115	5-536
Sokorodji	21	145	6-1018

BR Ntare, AT Diallo and F Waliyar

Project 4

Producing more and better food from staple cereals (sorghum and millets) and legumes (groundnuts, chickpea and pigeon pea) at lower cost in eastern and southern African (ESA) SAT through genetic improvement

Output 4A: Sustainable regional breeding networks that integrate conventional and biotechnology tools established; and improved germplasm and parental lines of adaptable sorghum, pearl millet, pigeon pea, chickpea and groundnut that are resistant to biotic stresses and meet end user preferences developed and disseminated with associated capacity development annually in ESA

MTP Output Target 2006: At least 10 new groundnut lines with increased rosette virus resistance made available to partners

Output Targets A1: Task networks established to pursue regionalized breeding in response to determined sorghum and millet regional challenges [2011]

Activity A1.1 Enhance capacity on the use of GIS and establish recommendation domains for technology targeting by task networks for sorghum and millet improvement for food security and market needs

Milestone A1.1.1: At least 10 NARS collaborators trained on GIS and other data/information management tools by 2007

Capacity building on tools, methods and strategies to improve crop breeding efficiency: Resources available for agricultural research have fallen sharply in many NARS and in International Agricultural Research Centers. The Sub Regional Organizations, such as ASARECA, are pursuing a regionalized approach to technology development, dissemination, scaling out and information sharing with a major goal of attaining efficiency and cost effectiveness. In order to develop improved sorghum and millet cultivars, the strategy is to establish breeding networks that will address regional crop improvement challenges that cut across the region. This requires a good understanding of the relevant plant adaptations for sorghums and millets in ECA, tools and methods that will help in methodical delineation of recommendation and scaling out domains. The concept of agro-ecological characterization and mapping the crop adaptation areas in the region of interest is a priority that can also support integration of crop improvement and natural resource management issues (IGNRM). ECARSAM and ICRISAT organized a training course for its collaborators on GIS and data and information management. The training course was conducted in Nairobi, Kenya and attended by a total of 22 participants (14 men and 8 women) including breeders, GIS and data management specialists from Kenya, Uganda, Tanzania, Ethiopia, Eritrea, Sudan, Rwanda and Burundi. The main achievements included:

1. Articulation with scientists the benefits to be derived from pursuing a regionalized crop improvement program citing experiences from southern Africa,
2. Exposure of scientists to GIS, and other tools and methods useful in developing strategy for sustainable crop improvement programs,
3. Identification of main production systems for sorghum and millets in ECA in view of biophysical-climatic conditions as well as socio-economic factors such as end use quality requirements in terms of food and market needs, industry needs e.g. food, feed, fodder to determine crop improvement needs, and
4. Clear identification of the environmental factors to which specific adaptation is expressed e.g. highland sorghum, photoperiodic sensitivity and determine studies to inform the crop improvement programs.

This was followed up by a training and refresher course to 10 scientists on biometry and statistical methods, how to organize, manage and analyze biodiversity and molecular data. Emphasis was placed on using Genstat 9.0 and other software's such as Numerical Taxonomic multivariate Analysis System (NTSYS), Arlequin, R.2.2 and Popgene. This training was considered very useful and plans are underway to expand it and include a broader range of scientists in ESA.

MA Mgonja, B Mitaru and E Manyasa

Milestone A1.1.2: At least one new breeding target identified in collaboration with regional networks to address evolving challenges for either sorghum or millet by 2009

Sorghum for bio-ethanol: Fuel prices skyrocketing and concomitant shrinking supplies have triggered efforts in exploring the use of alternative and renewable fuel sources. . One such alternative is bio-ethanol and many developing countries are racing for bio-ethanol production. In recent years sweet sorghum (*Sorghum bicolor* L. Moench) stalks are emerging as viable alternative sources. Comparative advantages for the use of sweet sorghum, status of available technology, challenges and opportunities on the use of sweet sorghum based ethanol have been articulated. NARS partners of South Africa, Zimbabwe and Kenya have shown interest in this area and ICRISAT-ESA envisages working in collaboration with diversified range of partners from these countries. The main focus will be to establish a holistic and integrated system that will look into the sweet sorghum germplasm identification, adaptation testing, linking it with the seed systems and processing technologies. To kick off this new intervention, germplasm have been acquired from ICRISAT India (22 varieties and 45 hybrids) and also from the ESA region for preliminary evaluation for adaptability and also for identification of the most productive varieties. The evaluation has been initiated in 2006/07 season in Kiboko, Kenya and Matopos in Zimbabwe. The expected outcome will be expanded sweet sorghum utilization in the bio-ethanol production to expand livelihood opportunities and environment protection

MA Mgonja and E Manyasa

Milestone A1.1.4: At least one group of NARS working together for pearl millet improvement by 2007

Pearl millet breeders have released a number of improved varieties (11 in ECA and 19 in SADC) that are high yielding potentials and adaptable to the targeted environments. However, production and productivity has remained low due to the continued use of low yielding landraces, poor crop production practices under environments with declining fertility. A proposal was developed by ICRISAT in collaboration with NARS partners from Eritrea, Sudan, Tanzania and Kenya and was funded in 2006 by ECARSAM through the Competitive Grant System. The proposed project is IGNRM oriented and focuses on introducing genetically superior varieties and environmentally friendly integrated production practices to increase production and productivity. By integrating findings on soil and water management, variety improvement, crop protection, farmer seed knowledge, production and delivery systems and environment conservation awareness, the project will be putting to use cumulative findings from related scientific departments and disciplines in the region over periods of time for the benefit of the current pearl millet farming community.

Use of GIS will ensure effective environmental placement of integrated production packages during validation and evaluation to save in both time and resources. Pooling of review and validation findings across partner countries will enhance sharing of scientific findings from these. Inclusion of the farmers and extension personnel will ensure sense of ownership of the findings and sustainability of the technologies.

In preparation for effective implementation of the project, NARS collaborators from Zimbabwe, Sudan, Kenya and Tanzania participated in the International Pearl Millet Training course held in ICRISAT-India in May 2006 to sharpen skill on pearl millet improvement and seed production. The project's implementation period is 2007 to 2009

MA Mgonja and B Mitaru

Output Targets A2: Genetically diverse sorghum varieties tolerant to striga and midge developed in collaboration with NARS participating in breeding networks [2011]

Activity A2.1: Transfer *Striga* resistance in sorghum to elite African cultivars using marker-assisted selection

Milestone A2.1.1: Elite farmer varieties carrying 1 to 3 QTLs evaluated through a participatory approach (2007)

Flanking simple sequence repeats (SSR) markers to the QTLs in marker-assisted backcrossing is vital in transferring *Striga* resistance from the donor cultivar N13 to susceptible farmer preferred sorghum varieties (FPSVs). In this project entitled, "*Arresting the scourge of* Striga *on sorghum in Africa by combining the strengths of marker-assisted backcrossing and farmer-participatory selection*", NARS in the Kenya, Mali, Eritrea and Sudan are being assisted to strengthen *Striga* resistance of farmer-preferred sorghum varieties (FPSVs) through a combination of marker-assisted backcrossing (MAB) and farmer-participatory selection. Near-isogenic FPSVs carrying one to three *Striga* resistance QTLs are being developed. Simultaneously, studies are being undertaken to enhance the understanding of sorghum seed supply systems and to ensure the effective integration of seven *Striga*-resistant FPSVs into farming systems in Eritrea, Kenya, Mali and Sudan. The extent of outcrossing rates and gene flow are being determined in five selected FPSVs.

So far, 712 plants were genotyped from two backcross generations (BC_1F_1 and BC_2F_1) at the BecA research platform (ILRI; Nairobi, Kenya) using a total of 10 foreground SSR markers and 16 background SSR markers. Genotyping revealed that 256 plants from the second backcross generation (BC_2F_1) were heterozygous for 1 to 3 QTLs.

In Kenya, 43 BC_2F_1 plants were selfed and genotyped to select for segregating homozygous BC_2S_1 plants that have been taken through another selfing generation (BC_2S_2) to fix the QTLs. Plans are now underway to genotype the BC_2S_2 plants, and those confirmed to contain one to three QTLs will then be multiplied and evaluated for *Striga* resistance in artificially infested fields.

The selfing of 73 BC_2F_1 plants in Mali and 103 BC_2F_1 plants in Sudan has been completed and genotyping of the BC_2S_1 is now planned. The segregating homozygous BC_2F_1 plants will be selfed to fix the QTLs. Preliminary studies have revealed some variability in FPSVs with outcrossing rates ranging between 3 and 5%. Initial gene flow studies have shown pollen dispersal for distances of up to 100 m in multiple directions, with a marked decrease after 40 m from the center.

Activity A2.2: Develop Sorghum varieties resistant to Midge through marker-assisted selection.

Milestone A2.2.1: Markers segregating with traits associated with resistance to midge identified and linkage map of the F2 population of AF28 Seredo generated by 2007 (DK, TH)

Sorghum midge (*Stenodiplosis sorghicola* Coquillet), spotted stem borer (*Chilo partellus* Swinhoe) and sorghum shoot fly (*Atherigona soccata* Rond.) are the three most destructive insect pests of sorghum in the ASARECA (Association for Strengthening Agricultural Research in East and Central Africa) region. Midge control in sorghum, therefore, is one of the research priorities in ECARSAM (the Eastern and Central Africa Regional Sorghum and Millet Network), the sorghum and millet network of ASARECA.
Midge resistance in sorghum is location specific and the identification of sorghum genotypes with stable resistance to sorghum midge is therefore hampered by genotype × environment interactions. 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 objectives of this project are therefore to 1) identify SSR markers that segregate with traits associated with resistance to sorghum midge and 2) initiate MAS towards the development of midge resistant sorghum varieties to improve sorghum production in East Africa. The project aims to map midge resistance QTL in order to identify SSR markers closely linked to these QTL and to initiate the development of sorghum varieties with resistance to sorghum midge through MAS. So far the project, generated a segregating sorghum population for midge resistance using the highly resistant, locally adapted sorghum landrace from Africa AF 28 and Seredo, a high-yielding, drought tolerant, midge susceptible Kenyan sorghum cultivar. The resulting F_1's are now being genotyped in the ICRISAT/BecA lab using SSR markers to confirm their heterozygosity.

D Kiambi, D Hoisington, T Hash, S de Villiers

Output Target A3: Genetically diverse and regionally adapted germplasm and breeding populations of sorghum and millet developed and disseminated [2011]

Activity A3.1: Develop and evaluate traits and end use specific sorghum and millet populations and breeding lines for adaptation to specific environments and resistance to biotic stresses

Milestone A3.1.2: Conventionally bred midge, stem borer and leaf disease resistant lines for sorghum and millets evaluated in advanced trials for yield and adaptability by 2008

Sorghum midge [*Contarinia sorghicola*] is the most widely distributed of all sorghum insect pets. Host plant resistance and time of planting are some of the important components for the management of the pest. Several sources of resistance have been identified, however the levels of resistance vary from location to location. This calls for localized breeding and testing for sorghum midge resistance. A total of 155 conventionally bred midge resistant lines plus 5 checks were evaluated in a preliminary trial at Alupe, Kenya in the long rainy season 2006 under natural infestation. These lines were crosses between MR No.s 2, 3, 4, 6, 7, 8, 10, 17, 21 22 from ICRISAT India with IS 8613, IS 21016 and AF 28. The trial had two plantings; one early and the other 2 weeks after normal planting to ensure adequate insect pressure for midge damage evaluation. The first planting had a mean score of 3.4 midge damage on a 1-9 scale. 91 entries had scores of 1.0-3.0 midge damage showing high levels of resistance. Eighty eight entries had grain yields between 1.3 and 4.6t/ha and these high yielding lines corresponded to the 91 lines with low midge damage, an indication that at this site midge resistance enhanced grain yield. The second planting had a mean score of 7.4 midge damage (1-9 scale) and 29 lines showed moderate levels of resistance to midge with scores of 4-6 (1-9 scale) and with a grain yield potential of over 1.0 t ha^{-1} (trial mean 0.981 t ha^{-1}). In the second planting, all check varieties except for IS 8613 had grain yield <1.0 t ha^{-1}. Cross MR # 7 x AF 28-2-5-1-1-1 showed the best performance against midge with score of 4.0. These selections will be put into an advanced sorghum midge resistance trial in 2007 and supplied to interested NARS. A small preliminary sorghum midge resistance trial (12 entries) was also sent to Uganda and Ethiopia in April 2006 on their request and results of their evaluation are yet to be received.

MA Mgonja, E Manyasa and J Kibuka

Milestone A3.1.3: Performance and adaptability of the Bristled pearl millet variety ICMV221 (ICMV221 Br) line established by 2010

Development of bristled pearl millet population was initiated in the quest to address the perennial problem of bird damage in pearl millet production. Three bristled pearl millet population cycles were developed from the released variety ICMV 221. The bulked selections from the three cycles (C1, C2 and C3) plus C0 and check varieties KAT PM 1, KAT PM2 and ICMV 221 were evaluated for their performance at Kiboko and Kampi ya Mawe (Kenya) in 2005/06. Results showed that bristle density and length increased with increase in cycle with cycles 2 and 3 having the highest percentage of medium and long bristles (54.8, 13.6 % and 55.1, 18.8% respectively). Grain yields for C0 to C3 ranged from 0.474 to 0.939 t ha-1 compared to 1.365 t ha- for ICMV 221 with a decrease in yield with increase in cycle. However, at Kampi ya Mawe, C1 gave better grain yields (0.570 t ha^{-1}) compared to C2 and C3. But ICMV 221 (0.715 t ha^{-1}) still out-yielded all the population cycles. This trial has been established at Kiboko and Kampi ya Mawe in 2006/07 rainy season to evaluate the cycles for bird damage and results will be reported in 2007.

MA Mgonja, E Manyasa and E Muange

Output target A4: Improved sorghum and millet varieties and hybrids with end use preferred plant and grain traits developed, evaluated and disseminated [2011]

Activity A4.1: Develop and evaluate a wide range of varieties and hybrids that are adaptable and meet end use requirements

Milestone A4.1.4: Regional sorghum hybrid / variety trials with brown/red and white seeds evaluated annually in the short/medium season environments

A regional sorghum hybrid trial comprising of 8 hybrids developed at ICRISAT-Nairobi and 4 from ICRISAT-Bulawayo plus 4 parental checks (KARI Mtama 1, Gadam Hamam, Macia and Kiboko local 2) were evaluated at Kiboko and Alupe (Kenya) in long rainy season of 2006. Both trials were under rainfed conditions. The hybrids performed better than the checks at Kiboko with the best hybrid IESH 22019 (2.987 t ha^{-1}) yielding 126% better than the best parental check Gadam Hamam (1.319 t ha^{-1}). Hybrids IESH 22019, IESH 22002, IESH 22010, IESH 22011, SDSH 409, IESH 22012 and IESH 22005 attained grain yields above 2.0 t ha^{-1} (trial mean 1.885 t ha^{-1}). Similarly at Alupe also, the hybrids out-yielded the parental check varieties. The best hybrid IESH 22021 yielded 1.716 t ha^{-1} compared to the best parental check (Gadam Hamam) which yielded 1.420 t ha^{-1}. The regional trial was also sent to Tanzania, Zimbabwe and Malawi in the rainy season 2006/07 and results will be reported in 2007. A new hybrids test cross evaluation with 203 entries was also carried at Kiboko and Alupe in the long rainy season 2006 using hybrids developed using A/B/R lines from ICRISAT-India. Out of the 203 test hybrids, 25 at Kiboko and 14 at Alupe with good fertility restoration and agronomic potential were selected. The 25 selected hybrids at Kiboko have been put into a preliminary hybrid trial in the 2006/07 rainy season whereas the 14 selections made at Alupe will be planted in long rainy season 2007.

Forty nine advanced and 50 preliminary sorghum lines developed from crosses between bold grain B lines from ICRISAT- Bulawayo and adapted local and improved varieties to improve grain quality of the adapted varieties were evaluated at Alupe in the long rainy season 2006. Yields of the 11 best test lines in the advanced trial ranged from 2.292 to 2.736 t ha^{-1} with 100 seed mass >2.9gm. The best check variety (IESV 93036 SH) yielded 2.222 t ha^{-1}. The best lines will be evaluated at more sites and supplied to interested NARS. In the Preliminary yield trial, yields in the best 8 test lines ranged from 1.896 to 2.469 t ha^{-1} and were above the best check variety IESV 93036 SH (1.854 t ha^{-1}).

MA Mgonja, E Manyasa, J Kibuka and E Muange

Activity A4.2: Facilitate information, knowledge and product sharing among NARS partners of available improved sorghum and millets populations and germplasm

Milestone A4.2.1: At least 6 NARS are annually provided with breeding materials for further evaluation

The ICRISAT breeding program provides breeding materials as semi-and-finished products for further selection and testing by NARS collaborators. In 2006, breeding materials were provided to six NARS partners at their request for inclusion in their respective evaluation programs.

Breeding Materials supplied to Collaborators in 2006 (from ESA, Kenya)

Country	Crop	Organization	No. of varieties	No. of samples	Category	Quantity (kg)
South Africa	Sorghum	CSIR	20	20	Varieties/Advanced breeding lines	2.0
Kenya	Sorghum	Moi University	12	12	,,	1.2
Kenya	Sorghum	KEPHIS	54	54	,,	0.54
Uganda	Sorghum	SAARI/NARO	12	36	,,	0.12
Ethiopia	Sorghum	IAR	12	36	,,	0.12
Kenya	,,	KARI-Embu	26	75	,,	1.8
Kenya	,,	Western Seed Company	7	14	A/B lines	0.4
Botswana	,,	MOA-Research	1	1	Breeder	0.1
Sudan	Finger millet	Research	337	409	Germplasm/varieties	2.6

The materials are shared under the Material Transfer Agreement.

MA Mgonja and E Manyasa

Milestone A4.2.2: At least one improved sorghum and /or pearl millet cultivar released every two years in any ESA country from 2007 to 2011

Improved sorghum and millet varieties identified for release in Malawi: NARS collaborators continue evaluation of improved germplasm to identify the most adaptable and acceptable materials for release and cultivation by farming communities. The Malawi Agricultural Technology Clearing Committee (ATCC) met at Chitedze Research Station and considered several technologies including sorghum and millet materials derived from ICRISAT germplasm. The National sorghum and millet breeder submitted for consideration for release two sorghum varieties, one pearl millet variety and two pearl millet hybrids. Two sorghum varieties (Sima and SV2) were given pre release status based on the station performance data. SV2 is released in Zimbabwe (1987) and Sima is also released in Zambia (1989). Initially thought to be restricted in adaptation to medium long season southern Zambia, analyses of available multi environment trial data for the SADC region indicated that Sima is one of the varieties that possessed characteristics that Zambian farmers prefer; expressed highest mean yields (327gm/m2) and positive responses to favorable environments (β=1.0) and was also found to be relatively biologically more stable with a CV=70.6%. Sima is one variety that based on its performance and stability stand even a higher chance for regional registration especially now that it has been pre-released in Malawi, and Zimbabwe is also considering its release.

The pearl millet variety SDMV 90031 was granted full release and was described to be superior in yield and an excellent complement to the other two released varieties (Nyankhombo and Tupatupa). The two pearl millet hybrids were not considered favorably due to the inadequacy of the seed system to handle hybrid seed production. Current efforts will target on farm testing to generate data to facilitate full release of the two sorghum varieties Sima and SV2

MA Mgonja and S Kudita

Activity A4.3: Develop and use alternative seed delivery models to efficiently disseminate improved sorghum and millet cultivars for adoption

Milestone A4.3.1: At least 3 NARS are annually availed with sorghum and millet basic seed for further multiplication 2007-2010

Sorghum and pearl millet basic seed: The pearl millet variety ICMV 221 has been released in three ECA countries-Kenya, Uganda and Eritrea. 20 kg breeder seed of pearl millet variety ICMV 221 were sent to Uganda through the DANIDA program for multiplication. The seeds were multiplied and distributed to farmers in northern Uganda. The NARS in Zimbabwe, South Africa and Mozambique have also been supplied with basic seed for sorghum and pearl millet to the tune of 10-100kgs for further multiplication and use in the Challenge Program on Water for Food Project 1 on integrated crop varieties with soil fertility and water management to increase productivity and profitability for the Limpopo basin. Seed production was done mainly in Zimbabwe and the land areas involved were for Sorghum variety Macia (2.2ha), Sima (0.32ha); and Pearl millet variety PMV3 (0.32). Others included sorghum varieties SV3, SV4 and Chokwe; pearl millet varieties OK 1, PMV2, Kuphanjala 1, Kuphanjala 2 and Changara in relatively smaller quantities.

MA Mgonja and Sakile Kudita

Milestone A4.3.2: At least 6 NARS are availed with improved germplasm and participate in regional cultivar evaluation annually from 2007

ICRISAT in collaboration with ECARSAM has re-instituted regional cultivar evaluation as a platform for germplasm exchange, improve efficiency in identification of suitable varieties with broader adaptability and sharing data to support cultivar releases. The regional trials are composed based on agreed breeding zones and end use targets.

Table: Sorghum and Millets Regional trials Composed and Distributed - 2006/07

Country	Crop	Organization	Trial name	No. of varieties	No. of samples	Category
Tanzania	**Sorghum**	DARD	Regional sorghum hybrid trial	26	106	Varieties/ Advanced breeding lines
			Sorghum Photoperiod Trial	10		
Mozambique	,,	Research	Sorghum Photoperiod Trial	10	20	Varieties/ landraces
Malawi	,,	ICRISAT	Regional sorghum hybrid trial	16	48	Breeder (hybrids)
Mali	,,	ICRISAT	Sorghum Photoperiod Trial	7	7	Varieties/ landraces
Tanzania	**Finger millet**	DARD	Regional finger millet trial	16	96	Germplasm/varieties
Malawi	,,	ICRISAT	Regional finger millet trial	16	48	Germplasm/varieties
Kenya	**Pearl millet**	KARI-Embu	Regional pearl millet trial	16	48	Varieties
South Africa	,,	Research	Regional pearl millet trial	16	48	Varieties
Tanzania	,,	DARD	Regional pearl millet trial	16	96	,,
Namibia	,,	Ministry of Agric., Water and Forestry	Regional pearl millet trial	16	48	,,

Sorghum and Millet Variety evaluation, release and seed multiplication in Eritrea: ICRISAT's research collaboration in Eritrea started in earnest in 1995 when over 600 sorghum and 98 pearl millet lines were introduced from ICRISAT-Nairobi and evaluated at Shambuko (western lowlands), Halhale (mid-highlands) and Shieb (eastern lowlands). On-farm testing of farmer selections from these trials began in 1997 and one pearl millet variety [ICMV 221(Kona)], 5 sorghum varieties [ICSV 210 (Bushuka) and PP 290 (Shambuko) for western lowlands; 89 MW 5003 (Laba) and 89 MW 89 5056 for eastern lowlands; IS 29415(Shiketi) for mid-highlands] were released in the year 2000.

During the 2004/05 season the Ministry of Agriculture and NARI produced: 163 t of PP 290, 63 t of ICSV 210, 119 t of Gadam Hamam, 15.8 t of ICMV 221 and 6.6 t of Hagaz. All of this seed was distributed to farmers in the western lowlands in 2005. In the western lowlands, 57 farmers had been contracted to produce seed and were growing over 110 ha of sorghum variety ICSV 111 IN. One farmer by the name Ato Mebrahtu Asfaha grows 2000 ha of both seed and grain sorghum under irrigation at Tesseney. Farmers in Eritrea have adopted released varieties and a number of new lines are being multiplied in readiness for release and distribution to farmers during the 2006/07 season. With these new varieties, farmers are now achieving grain yields of over 1.5 t/ha compared to 0.8 t/ha from local varieties

In the mid-highlands of Eritrea, IESV 92029 DL (bred at ICRISAT-Nairobi) has been earmarked for release and over 7 ha were under seed crop at Halhale. In the western lowlands, ICSV 111 IN has been earmarked for release and over 110 ha were under seed crop at Shambuko. The ICRISAT ESA breeding program have plans to carry out a Sorghum and millets adoption and impact study in Eritrea during the 2007 season.

MA Mgonja, B Mitaru and E Manyasa

Activity A4.3: Develop and use alternative seed delivery models to efficiently disseminate improved sorghum and millet cultivars for adoption

Milestone: A4.3.3: Business plans developed for establishment of Seed Enterprise Enhancement and Development Services [SEEDS] in at least three countries of ESA by 2007

Seed Enterprise Enhancement and Development Services: Farmers in many countries in Africa are unable to obtain high quality seed of improved publicly developed varieties due to a lack of effective commercial seed production distribution networks. There is a need to facilitate the introduction of both commercial and publicly developed varieties through distribution networks in a sustainable manner. This will expand farmers' selection and allow them to choose what best suits their requirements.

The African Seed Trade Association (AFSTA) and the ICRISAT program for the Sustainable Commercialization of Seeds in Africa (SCOSA) have proposed the establishment of Seed Enterprise Enhancement and Development Services (SEEDS) to support the development of small and medium-sized seed companies. These will include independently run and financially sustainable foundation seed enterprises (FSEs) that will market foundation seed of publicly developed varieties for use by seed companies without their own breeding programs. They will also provide access to seed storage and processing facilities to existing and emerging seed entrepreneurs. SEEDS will provide technical and business development support to seed entrepreneurs who will become the customers of the FSEs, ensuring their sustainability.

In 2006 national teams from Ethiopia, Kenya, Tanzania, Uganda, Malawi, Mozambique, Zambia, Zimbabwe, Botswana and Angola were trained in business plan development and then supported to hold national consultation meetings needed to solicit input into their respective business plans. An Excel template was developed to assist in the preparation of financial projections, and these will be used to solicit for funding from interested development investors in 2007.

RB Jones

Output Targets A6: High yielding farmer and market-acceptable groundnut varieties developed

Activity A6.1: Identify through PPB and introgress groundnut germplasm for yield components farmer/market preferences and adaptation with special reference to incorporation of drought tolerance in short duration Spanish types with fresh seed dormancy

Milestones A6.1.1: At least 3 farmer/market preferred varieties incorporating drought tolerance in short duration background? released in 2–3 ESA countries (2010)

Breeding material incorporating Adaptation Traits: Groundnut breeding in ESA is targeting the following traits for adaptation, farmer and market preferences

1. Fresh seed dormancy in short duration varieties
2. Large seeds in short duration varieties
3. Large seeds and high yield in medium to long duration varieties
4. Grading qualities as measured retention above sieve 19 compared to CG 7 and Chalimbana.

Fresh seed dormancy is essential among early maturing varieties of groundnut to avoid sprouting in field. Advance progenies with fresh seed dormancy from the segregating nurseries. Eight progenies from 4 rosette nurseries were identified. It was interesting to note that fresh seed dormancy was not found among the Dormancy and Rosette resistance - F7s in spite of the fact that the nursery originated from crosses involving parents with fresh seed dormancy. This finding will need further investigation.

Elite Short Duration Drought Tolerance and Dormancy Trial: the best two entries were ICGV-SM 98511 and ICGV-SM 86021 with grain yields 102 – 115% of JL 24 (1.7 – 2.0 t ha^{-1}). None of the entries were better than ICGV-SM 99568 (2.2 t ha^{-1}) which is both early maturing and resistant to rosette. However the rainfall in Southern Malawi (Drought screening site) was higher than normal during the season, providing a good opportunity for fresh seed dormancy screening. Sprouting was not a problem at this site – indicative of acceptable levels of fresh seed dormancy

Elite Drought Resistant Groundnut Variety Trial: ICGV-SM 03535, ICGV-SM 03521, ICGV-SM 03502 and ICGV-SM 03510 had grain yields ranging from 2.4 t ha^{-1} to 3.3 t ha^{-1} (153–208% superior in yield as compared to the standard check JL24).

Large seeded germplasm and grading qualities are highly sought after in the groundnut confectionary market. From the Short duration large seeded nursery, the best three lines were ICGV-SM 00528, ICGV 94536 and ICGV-SM 00503 with yields 111 – 148% of the standard check JL 24 but acceptable confectionary size nuts. From the Elite High Yield and Quality Groundnut Variety Trial (Spanish), four lines ICGV-SM 03552, ICGV-SM 03564, ICGV-SM 03573 and ICGV-SM 03576 had grading qualities and yield similar or better than the newly released variety ICGV-SM 99568. Yield was 2.6 t ha^{-1} as compared to 1.9 t ha^{-1} for ICGV-SM 99568 and are resistant to rosette disease.

From the Elite High Yield and Quality Groundnut Variety Trial (Virginia), ICGV-SM 01721 was identified with 100 seed grain weight significantly higher than CG 7 but the yield was only 93% that achieved from CG 7. Four lines with grading qualities and yield similar to CG 7 and Chalimbana with combined advantage of rosette resistance were identified. These are ICGV-SM 02707, ICGV-SM 02715, ICGV-SM 02724, and ICGV-SM 01731. All these lines had grain yields significantly higher than that of the check Chalimbana.

New Variety Release(s)

ICGV-SM 99568 for the rosette constraint in Malawi under the local name Chitala, and ICGV 94297 in Zimbabwe under the local name Ilanda.

ES Monyo

Activity A6.2: Develop and evaluate diverse groundnut breeding populations, lines and varieties while developing the capacity to screen for GRD, foliar disease resistances and aflatoxin contamination in the NARS

Milestone A6.2.1: Infector row technique for screening of GRD resistance established and operational with at least one NARS in ESA by 2008 (ESM)

2006 - Targeted milestones:

- Diverse populations of groundnut developed through conventional and marker assisted selections
- Local germplasm deployed in the breeding program for incorporating specified traits (e.g. adaptation, yield grain type and disease resistance)

Diverse breeding populations, lines and varieties and capacity to screen for GRD and foliar diseases (rosette, ELS, LLS, and rust). The infector row technique is currently in use at the ICRISAT Chitedze Research Centre with Malawi NARS.

The rosette disease pressure was excellent. There was 100% infection in the spreader rows and susceptible checks. The observed resistant progeny selections above were therefore a true reflection of genetic resistance in the selected progenies.

From 16 nurseries ranging from F4 – F6 in 1003 progeny rows, a total of 636 plants were identified for generation advance through single plant selection. Out of these we identified 58 single plant selections from 8 of the nurseries with 0% rosette incidence (9% of total) and an additional 66 plants with rosette incidence ranging 1 - ≤ 20%.

From seven F7 nurseries with 468 progeny rows, a total of 323 were selected for promotion to checkrow trials, out of which 91 had 0% rosette incidence.

Most of the inter-specific derivative progenies exhibited susceptible reaction to ELS. Even the 13 selected single plants had relatively higher ELS than many of the selections from other nurseries. This finding has implication on the nature of resistance and inheritance of ELS from wild *Arachis* that may need further investigation.

There are excellent progenies both in Check row trials and in F7 that combines ELS and rosette resistance. As seen in the table above, our efforts of pyramiding these two constraints are starting to pay off.

Good progress has been made in identification of ELS resistant progenies received from ICRISAT-Patancheru. From an initial nursery of 443 F2 planted in 2004, we have identified 80 progenies with very good levels of resistance to ELS for promotion to F4 families. In pyramiding ELS resistance genes, 240 F5 single plant family progenies have been selected for generation advance to F6 in ELS x ELS crosses and 48 single plant family progenies identified in F4 combining ELS resistance with confectionary market traits.

Achievements on single plant selection program for segregating breeding populations in the Rust and LLS nursery: There were three segregating population nurseries:

- From 104 F6 Rust and LLS Resistance screening nursery, 81 families were identified for generation advance
- From 1673 F7 Rust and Rosette Resistance nursery a total of 408 families were selected to make two sets of checkrow trials each comprising 204 entries
- From 216 entries of the checkrow trial, 62 lines were identified to develop Preliminary Rust and LLS Trial each consisting of 31 entries plus checks (36 entry trials)

The disease pressure for 2006 was low hence most of the selections were based on yield and adaptation to the Low altitude hot humid environment of the Malawi Lake Shore.

ES Monyo

Lead NARS crop improvement Networks for Groundnut Research in ESA:
Through the McKnight Foundation that funded a project on “Developing short-and medium-duration groundnut varieties with improved yield performance, acceptable market traits and resistance to foliar diseases”. This project

will be implemented through research task networks in Tanzania and Malawi based on competitive advantage for the researchable constraints while building capacity to tackle these constraints at national level. In particular Tanzania's Naliendele Research Station will focus on Rust resistance screening while Chitedze in Malawi will focus on Rosette and ELS.

ES Monyo

Output Target A7: Adoption rates of improved farmer and market-acceptable groundnut varieties and production technologies enhanced

Activity A7.1: Enhance institutional innovations to improve access of the poor to good quality seeds of improved high yielding adapted groundnut varieties and conduct training of trainers program on seed production techniques

Milestone A7.1.2: At least 1 ton breeder seed of 3 released farmer/market preferred varieties in ESA produced annually as source for foundation seed for collaborating NARS and other Partners 2007-2011

Institutional Innovations to improve access of the poor to good quality seed: Efforts to promote adoption rates of farmer and market acceptable varieties were linked to institutional building through the Challenge Program on Water for Food. Seed for implementation of activities to initiate crop water productivity on-farm trials for the 2005-06 season was produced and supplied to partners as follows:

- Seed enough to implement 96 mother trials and over 600 baby trials in Zimbabwe; 9 mother trials and 19 baby trials in Mozambique – (groundnuts, sorghum and pearl millet).
- Varieties of the various crops important in the basin for use with the crop water productivity studies have been documented as follows: Sorghum (Macia, SV1, SV2, SV3, SV4, Sima and Chokwe), Pearl Millet (Okashana 1, PMV2, PMV3, Kuphanjala-1, Kuphanjala-2 and Changara), Maize (ZM 421, ZM 403, and ZM 521) and groundnuts (Jesa, Nyanda, Ilanda, Mwenje, JL 24, Sellie, Nematil). Concerted efforts for seed production were concentrated in a few preferred varieties from the list – particularly Macia for sorghum, PMV3 for pearl millet, Nyanda and Nematil for groundnuts, ZM 421 and ZM 521 for maize.
- During 2006–07 the following seed production activities were implemented by ICRISAT and NARS in Zimbabwe under off season for the 2006-07 trials: Sorghum variety Sima 0.32 ha, Macia 2.2 ha, Pearl Millet variety PMV 3, 0.32 ha and groundnut variety Mwenje 0.8 ha at Chiredzi Research Station.
- The following varieties and quantities of groundnut seed were produced for CPWF-CP1 on-farm trials and demonstrations: Nyanda; 650kg, ICGV-SM 01513 200kg, ICGV-S, 99541 97kg, ICG 12991, 900kgs. A total of 440 kgs was sent to Mozambique for trials.

Milestone A7.1.1: At least 5 kg nuclear seed of each of 15 varieties in Regional Trials produced annually as source for breeder seed and entries for collaborative trials with NARS in ESA 2007 – 2011

Other non CPWF-CP1 seed production efforts resulted in the following achievements;

- 2–5 kg nuclear seed for 129 varieties of groundnuts in Advanced and Elite Trials produced
- 2203 kg breeder seed of the Aphid resistant variety ICG 12991
- 3759 kg breeder seed of the groundnut rosette virus resistant variety ICGV-SM 90704

ES Monyo

Milestone: A7.1.3: One new institutional arrangement for supply of legume seed tested in Kenya in 2006

New institutional arrangement: Analysis of groundnut value-chains has identified market opportunities for farmers producing surplus groundnuts, but the variable quality and limited supply of marketable surpluses constrains their ability to attract premium prices. Traditional formal seed production schemes result in high seed costs resulting in limited seed demand through such channels rendering them unsustainable. In 2006 a new institutional arrangements was designed and tested whereby a private seed company marketed improved groundnut foundation seed to organized groups of seed farmers identified by the communities in which they live. These seed farmers were then lined to a farmer owned company to market seed to other farmers in these and other communities where these crops were being promoted. Preliminary results suggest that this institutional arrangement builds upon the strengths of informal seed supply systems that most smallholder farmers rely on, but enhances the choice of varieties available to such farmers from research, and that this leads to increased productivity and improved quality on the part of buyers.

RB Jones

Output target A8: Adapted germplasm of pigeon pea with enhanced productivity and desirable traits [2010]

Activity A8.1: Develop genetically enhanced and regionally adapted pigeon pea germplasm

Milestone A8.1.1: At least 3 high-yielding medium-duration pigeonpea cultivars adapted to the ecological and cropping systems in southern Africa developed by 2009

Photoperiod sensitivity in both medium- and long-duration pigeonpea was one of the limitations for increasing productivity of pigeonpea particularly around equator (10^{o} to 20^{o} north and south) areas in ESA. In such areas, flowering and maturity are delayed thus rendering the crop prone to terminal drought stress and winter frost. Newly developed early to medium-duration (photoperiod-insensitive) cultivars developed for southern Africa were evaluated at Chitedze Research Station (13^{o}59' S and 33^{o}44' E), Malawi during the 2005/06 cropping season. Several traits including the number of days to 50% flowering (50%DF), number of days to 75% maturity (75%DM), grain size (100-GW) and yield were measured. There was variability in 50%DF among the cultivars ranging from 83 d (ICEAP 01514/15) to 112 d (ICEAP 01160/15). In comparison, the preferred and popular local check variety (Mutawajuni) and commercial cultivar (Royes) required 83 d and 119 d respectively to attain 50%DF. Cultivar ICEAP 01514/15 matured significantly ($P<0.05$) earlier (153 d) than both Royes (173 d) and Mutawajuni (172 d). Royes obtained the smallest (100-GW = 13.1 g). However, 100-GW of the improved cultivars ranged between 13.6 - 15.5 g. The highest grain yield (3.0 t/ha) was observed for the cultivar ICEAP 01480/32 compared with 1.0 t/ha attained by Royes. Similarly, cultivar ICEAP 01514/15 obtained 2.9 t/ha.

SN Silim and E Gwata

Milestone A8.1.2: At least 3 early short-duration cultivars that can escape terminal drought stress in ESA developed by 2009

Some parts of ESA, such as the eastern in Kenya, experience a bi-modal rainfall pattern with the first season lasting only three months (November to January). Short-duration pigeonpea varieties that provide flexible options for pigeonpea farmers, are ideal for these conditions. Evaluation of determinate short-duration types was conducted at Kiboko Research Station in eastern Kenya. Six lines averaged >1.0 t/ha compared with 0.5 t/ha obtained for the check cultivar ICPL 87091. On average, the cultivars required 87 d to achieve 50% flowering. ICEAP 01134 developed the largest grains (100-grain weight = 14.1 g) compared with the small (100-grain weight = 12.3 g) observed for the check cultivar. In the advanced variety trial, 14 experimental lines averaged 1.6 t/ha. The genotype ICEAP 01275 obtained the highest grain yield (1.97 t/ha) which was 25% more that the yield observed for the check cultivar ICPL 90050. In another field trial conducted at Ilonga (Tanzania), ICEAP 00624 attained the highest (1.24 t/ha) and required 57 d to achieve 50% flowering.

One of the major drawbacks in our 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 and E Gwata

Activity A8.2: Widen genetic base of pigeon pea with enhanced resistance to fusarium wilt

Milestone A8.2.1: Collection of pigeon pea from Tanzania and Mozambique screened for resistance to fusarium wilt by 2008

Preliminary evaluation of germplasm (previously collected from Tanzania and Mozambique) for resistance to *Fusarium* wilt was conducted in a wilt-sick plot at Kiboko (Kenya).There were 12 (one from Mozambique and 11 from Tanzania) accessions with medium to high resistance levels. Further evaluation of these accessions is in progress. Similarly, the elite medium duration cultivars developed for areas away from the equator were also included in the wilt-sick plot for the 2006/07 season. Although genetic material showing resistance in this wilt-sick plot at Kiboko is expected to show wide amplitude resistance elsewhere in ESA, these preliminary results should be interpreted with caution. Differential host responses to the disease have been demonstrated in previous studies in ESA. Nevertheless, sources of resistance to the disease in locally adapted material will be useful in pigeonpea breeding programs in the region.

SN Silim and E Gwata

Milestone A8.2.2: Pigeonpea breeding populations derived from resistant x adapted germplasm developed by 2009

Crosses between the resistant germplasm (originating from both Mozambique and Tanzania) and adapted cultivars in both medium- and long-duration pigeonpea types (and their reciprocals) were initiated at both Kiboko and Kampi ya Mawe. The major target is to introgress the resistance to wilt particularly in the early medium-duration types developed for areas away from the equator. Likely, some of the germplasm lacks adequate levels of resistance to the disease since photoperiod insensitivity was the main focus of the initial improvement effort. F_2 populations derived from a landrace (popular in Malawi, Mutawajuni) x resistant cultivars (ICEAP 00040 and ICEAP 0576-1) were raised in the field at Kabete, Kenya. The segregating populations will be shared with the prospective national programs to facilitate selection in target production areas. The selection criteria from this batch of crosses will include resistance to the wilt and insect pests as well as white (cream) seed coat desirable in the market.

SN Silim and E Gwata

Milestone A8.2.3: Selection and evaluation of resistant pigeonpea germplasm initiated by 2011

Medium- and long-duration pigeonpea cultivars require more than three months to mature in ESA. This makes these types prone to the wilt disease. All newly developed germplasm in both maturity groups needs to be evaluated in high-disease pressure conditions such as provided by wilt-sick plots at Kiboko (Kenya) and Ilonga (Tanzania). The selection process was initiated at Kiboko where the improved resistant long-duration cultivars (ICEAP 00040, ICEAP 00020, ICEAP 0576-1 and ICEAP 00933) were identified originally. Moderate levels of wilt resistance were observed for the medium-duration cultivars ICEAP 00554 and ICEAP 00557. It is desirable to establish similar testing facilities in the other countries such as Mozambique where the disease is prevalent. In addition, research effort directed toward identification of pathogenic races of the wilt disease across the region would be merited.

SN Silim and E Gwata

Milestone A8.2.4: Report/article on performance of resistant pigeonpea germplasm in ESA published by 2011

A multi-location evaluation of elite pigeon pea cultivars previously identified as resistant to fusarium wilt was conducted in three countries (Kenya, Malawi and Tanzania). The agronomic performance of the germplasm was communicated (*Journal of Plant Pathology 154: 62-64)* in 2006. The long-duration cultivar ICEAP 00040 showed stable resistance across the region. It was released for commercial production in both Malawi and Tanzania.

SN Silim and E Gwata

Activity A8.3: Test and select improved pigeonpea varieties for provision to NARS and further dissemination

Milestone A8.3.1: Evaluate, promote and disseminate through participatory/ on-farm methods, at least 6 newly improved pigeonpea cultivars for production in ESA by 2009

Seed of elite pigeonpea cultivars was disseminated to partners in southern Africa for the 2006/07 cropping season. In Malawi, where the crop is grown mainly in the southern region, on-farm evaluation in both the central and northern regions was initiated for the 2006/07 cropping season. In Tanzania, seed was disseminated to new pigeonpea areas (Karatu and Mbulu districts). Our partners (Diocese of Mbulu-CRS and the Selian Agricultural Research Institute) facilitated the expansion of the area under pigeonpea in Tanzania. In addition, a group of 16 media practitioners representing various international agencies (such as BBC East Africa, Kenya TV Network, Tanzania Newspapers) participated in a three-day field visit to Babati, Karatu and Mbulu (Tanzania) aimed at high-lighting the impact of pigeon pea in ESA as well as the critical role of ICRISAT in farmer-driven research. The wilt resistant cultivars (particularly ICEAP 00040 and ICEAP 00053) developed by ICRISAT were adopted widely in the area. In Kenya, pigeonpea was promoted through field days held in Makueni district.

SN Silim and E Gwata

Milestone A8.3.2: Promote participatory community-based methods for seed production of farmer-preferred pigeonpea cultivars in at least 3 countries in ESA by 2009

Farmer-training in the agronomy of pigeonpea is a continuous process as new farmers adopt the crop. During the pre-season (in 2006), farmers in Makueni district (Kenya) were trained in various aspects of pigeonpea production including the methods and techniques for improving seed quality. In Malawi, the on-farm demonstration plots established for the 2006/07 season will be used also for training farmers in community based seed production. It is anticipated that the farmers (particularly those new to the crop in the central and northern areas) will be trained in basic seed production techniques such as rouging off-types using phenotypic characters at both vegetative and reproductive phases, scouting for pests, crop isolation, seed cleaning and storage.

SN Silim and E Gwata

Output Target A9: High yielding and adapted chickpea germplasm for small-holder farmers identified and disseminated in ESA [2011]

Activity A9.1: Identify genetically enhanced chickpea germplasm adapted for production in ESA

Milestone A9.1.1: At least 30-40 high-yielding advanced chickpea lines/breeding lines (from ICRISAT Patancheru) evaluated in regional field trials in eastern and southern Africa by 2008

Evaluation of chickpea lines for adaptation to prevailing agro-ecological conditions in ESA was conducted in Kenya and Mozambique. The field trials consisted of both *desi* and *kabuli* chickpea types. In Chokwe district (Mozambique) three *desi* genotypes obtained high (>3.0 t/ha) grain yield. The highest (3.6 t/ha) grain yield was observed for ICCV 97126. The control cultivar (Ngara Local) attained 2.5 t/ha. The grain size (as measured by 100-grain weight) of the *kabuli* types ranged between 29.1 – 43.6 g. In contrast, the maximum grain size among the *desi* types was 30.g. At Kabete Research Station (Kenya), the *kabuli* cultivar ICCV 92311 attained 4.2 t/ha compared with 2.6 t/ha for Ngara Local. Eight *desi* and 12 *kabuli* cultivars achieved >3.0t/ha. It is desirable to extend the field evaluation of chickpea to other countries in ESA (Malawi, Tanzania and Zimbabwe) partly because of the genotype x location interaction observed in the trials.

SN Silim and E Gwata

Milestone A9.1.2: 10-15 high-yielding desi and kabuli type breeding lines identified in at least 2 ESA countries (Kenya and Mozambique) by 2009

In Kenya, 5 *kabuli* cultivars showed consistently high (>3.0 t/ha) in the previous three consecutive cropping seasons. In comparison with *desi* types, the *kabuli* types are more lucrative on the international markets. Nevertheless, significantly more *desi* cultivars (in the current germplasm) performed equally well thus providing the local farmers wider options. Similarly, in Mozambique, 80% of the high-yielding elite cultivars were of the *desi* type. There were no significant differences in maturity duration between the two chickpea types at either location indicating that the *kabuli* germplasm evaluated in these trials is adapted to tropical conditions in ESA. Historically, the *kabuli* types are adapted to cool temperate conditions. Therefore *kabuli* types adapted to tropical conditions as represented by Kenya and Mozambique were identified successfully. Probably, the next phase of the research effort should evaluate these new cultivars on-farm in order to facilitate their adoption as well as seed dissemination.

SN Silim and E Gwata

Activity A9.2: Identify chickpea germplasm with drought avoidance traits

Milestone A9.2.1: A sub-set of chickpea reference collection (from ICRISAT Patancheru) with selected root traits evaluated in regional field trials in at least 2 countries in eastern and southern Africa by 2010

The work under this activity is anticipated to begin in 2007 pending availability of funding. Preparation for the work is in progress.

Activity A9.3: Share seed of improved pigeonpea and chickpea germplasm with drought tolerance with partners in ESA

Milestone A9.3.1: Nucleus/breeder seed of at least 10 pigeonpea and 20 chickpea cultivars/ advanced lines available for sharing with NARS multiplied by 2009

In 2006/07 cropping season, the production of breeder seed was increased to include two locations (Kampi ya Mawe and Kabete Research Stations) in Kenya. For pigeonpea, it is necessary to cover the crop with nets during the flowering period of the crop to avoid cross pollination. Production of breeder seed of five wilt resistant and eleven pigeopea cultivars is in progress at Kabete and Kampi yaMawe respectively. Breeder seed of 13 chickpea advanced lines was also produced in 2006 at Kabete. Samples of the breeder seed will be stored for medium-term in the mini-gene bank at ICRISAT-Nairobi and the remainder will be shared with partners to produce foundation or certified seed.

SN Silim and E Gwata

Milestone A9.3.2: Seed of improved pigeonpea and chickpea germplasm disseminated to at least 4 NARS/ countries in ESA by 2008

The high level of out-crossing (30%) in pigeonpea poses a challenge to farmers in terms of maintaining cultivar purity. Therefore it is necessary to disseminate high quality seed to national programs for multiplication and distribution to farmers. Samples of clean breeder or foundation seed were shared with partners in Malawi, South Africa, Sudan, Tanzania, Uganda and Zimbabwe.

For chickpeas, the national programs (in Eritrea, Kenya and South Africa) as well as other partners (Catholic Relief Services and Egerton University) received seed. Requests for seed have also been received from Rwanda and Zimbabwe. In Mozambique, adequate stocks of high quality seed are available to both the national program and NGOs. It is evident that the demand for seed of these two legumes in ESA has increased significantly necessitating the legume enhancement program (at ICRISAT-Nairobi) to respond positively and ensuring availability of the germplasm.

SN Silim and E Gwata

Milestone A9.3.3: Farmers' access to legume seed in at least two ESA countries enhanced through collaboration with at least one public/private partnership (NARS/NGO/Private Seed Company by 2010

Collaborative efforts in seed multiplication with the private sector were initiated in at least two countries in ESA. In Kenya, a private seed company (Leldet Ltd.), with assistance from the Kenya Plant Health Inspectorate Service, agreed to undertake multiplying seed of ICRISAT chickpea (four) and pigeon pea (three) cultivars. Similarly, in Tanzania a seed company (Rotian Seed Company) initiated seed multiplication jointly with ICRISAT. The company is multiplying two cultivars (ICEAP 00040 and ICEAP 0053) in particular which are in high demand in Tanzania. The seed requirement for the two cultivars already exceeds 6.0 t in Babati district.

The partnerships with private companies are expected to rise with the increase in demand for legume seed in the region. Apart from providing the seed, ICRISAT provides technical support to the seed companies. This model of seed production is still being developed with the hope that eventually, it can be scaled-up to include other countries in ESA.

SN Silim and E Gwata

Milestone: A9.3.4: New institutional models designed and tested to enhance the availability of improved groundnuts, pigeon pea and chickpea seed through commercial channels by 2009

New institutional models: In Mozambique foundation seed of improved pigeonpea varieties from a Foundation Seed Enterprise (FSE) was marketed to a farmer-owned company for further multiplication into certified seed. This was then sold to farmers linked to a pigeonpea processing factory producing *dhal* for export. Preliminary results suggest that this institutional arrangement builds upon the strengths of informal seed supply systems that most smallholder farmers rely on, but enhances the choice of varieties available to such farmers from research. The availability of uniform grain from a single variety reduces the losses associated with processing, and creates incentives for agro-processors to introduce price premiums for quality that stimulate sustained investment in improved seed.

RB Jones

Output Target A10: Pigeonpea and groundnut transformation protocol developed in Asia applied to locally adapted varieties in ESA [2009].

Activity A10.1: Establish tissue culture protocol for various local pigeonpea and groundnut varieties

Milestone A10.1.1: Evaluate and establish seven locally adapted pigeonpea varieties in tissue culture (2006)

Seven pigeon pea varieties, adapted to the ESA region, as well as the Indian variety ICPL 88039 which was used as control, were introduced into tissue culture in the Kenya Agricultural Research Institute's Biotechnology laboratories. The varieties were from different duration types as well as those with resistance to *Fusarium* and included ICPL 86012, ICPL 87091, ICPV 00020, ICPV 00040, ICPV 00053, ICPV 00554 and ICPV 00447. The tissue culture responses of the different varieties were evaluated for suitability for subsequent transformation. All seven ESA adapted varieties responded well and it was possible to regenerate rooted plants from seed explants of all the varieties. However, the medium (ICPV 00554 and ICPV 00557) and short duration varieties (ICPL 88091 and ICPL 86012) reponded best and ICPV 00554 and ICPV 00557 will be used in transformation studies in 2007.

S de Villiers, D Hoisington, E Gwata, E Manyasa and S Silim

Output 4 B: New knowledge of the QTLs for the stay green trait confirmed, marker assisted selection efficiency improved, specific abiotic stress tolerant varieties and associated knowledge and capacity building measures for sorghum, pearl millet and groundnuts developed and disseminated annually in ESA from 2009 onwards

MTP Output Target: 3 partners received training in generation and interpretation of marker data for MAS in sorghum (Staygreen and Striga)

Output target: B1: 2 QTLs for stay-green introgressed into Sorghum farmer varieties (2008)

Activity B1.1: Develop marker assisted breeding of the stay- green trait of sorghum to enhance terminal drought tolerance in East African farmer-preferred varieties.

Milestone B1.1.1: Capacity of the NARS in marker assisted breeding technologies enhanced through MSc. training by 2007 (DK, TH)

Milestone B1.1.3: Efficiency and effectiveness of marker assisted breeding for stay-green trait in sorghum backgrounds determined by 2008

Attempts by plant breeders to exploit genetic variation for drought tolerance through conventional methods to improve grain yields have proven slow and ardous. However, molecular marker technology has provided powerful tools needed to dissect complex traits such as drought tolerance. A series of backcrosses has already been initiated to transfer the stay green trait from donor parents B35 and E 36-1 into a wide range of elite tropically adapted sorghum varieties including S35, Macia, ICSV 111 and ICSV 112 which are currently grown by resource-poor farmers in Africa. African adapted open pollinated varieties I ICSV 112, Macia and S35 have been advanced from BC1 to BC2 for stay green donor E-36 using SSR-based marker assisted selection targeting 6 stay green QTLs that were detected. During the process, foreground selection has been made to select QTLs of interest and background selection has been undertaken to select for all the loci of the recurrent parent. Near isogenic lines could then be developed for individual stay green QTLs so that the physiological responses associated with individual QTLs controlling various components of the stay green traits and interactions among these QTLs can be dissected. Consistently identified QTLs are therefore good candidates for marker assisted introgression into locally adapted varieties.

However, before marker assisted selection for stay green is applied widely in breeding programs that target extremely drought stressed environments, the benefit of stay green for yield performance and stability should be proven in target areas. This project therefore aims to transfer the terminal drought tolerance genomic segments (QTLs) in donor parents B 35 and E 36-1 into five commercial, locally adapted, open pollinated farmer-preferred sorghum varieties in Kenya, Uganda, Eritrea, Ethiopia and Sudan. Subsequently, the efficiency and effectiveness of marker assisted breeding for stay green trait in sorghum backgrounds selected from these countries will be determined. An integral part of the project's objectives is to enhance the capacity of scientists in the participating countries in marker assisted breeding technologies. To this end, a one-week a training course for seven scientists, technicians and MSc students involved in the project was organized in November 2006 at the ICRISAT/BecA lab in ILRI,Nairobi. It was organized in collaboration with Nairobi University and the Kenya Agricultural Research Institute (KARI). Participants were trained in DNA extraction, quantification and quality checks using agarose gel electrophoresis and purity tests using nanodrop spectrophometer. They were also trained in PCR optimization and genotyping using capillary electrophoresis. The project teams will now generate the backcrosses and using the skills gained, come back to the ICRISAT/BecA lab for genotyping.

D Kiambi and T Hash

Output Target B2: A diversified set of sorghum varieties tested for sensitivity to photo-periodism by 2011

Activity B2.1: Develop marker assisted breeding program for the photoperiod sensitive sorghum to enhance adaptability and productivity

Milestone B2.1.1: Capability of a diversified set of sorghum varieties to sense the rate of change of photo-periodism clarified by 2008 (MAM, SGM)

Work starts in 2007 and no progress is due for 2006

Milestone B2.1.2: Segregating populations for photoperiod sensitivity and stay green evaluated using molecular markers from 2009 (MAM, SGM)

Work starts in 2007 and no progress is due for 2006

Activity B2.2: Integrate drought tolerant sorghum and millet varieties with water management to improve productivity for sorghum and millet

Milestone B2.2.1: Adaptable drought tolerant varieties for evaluation with water management technologies identified by 2007

Participatory approaches to identify crop water productivity enhancing technologies (IGNRM)
Total crop production needs to increase under increasing water scarcity. The Challenge Program Water for food (CPWF) seeks to identify and deploy interventions that can contribute to increasing food production and saving or using water more efficiently. One of the interventions can be improvement of genetic resources (germplasm) for drought resistance and integrate these with water management technologies. The Challenge Program Water for Food Project no 1 focuses on integrating improved crop varieties with soil fertility and water management to enhance crop water productivity and partnership linkages with markets to improve profitability. Participatory approaches were deployed with NARS partners of Mozambique, South Africa and Zimbabwe collaborating in the CPWFPN1 to identify adaptable crop varieties for evaluation with water management technologies. These include released crop technologies of sorghum, pearl millet, maize, legumes and groundnut varieties. Exploratory field trials comparing the productivity (crop productivity as a measure of water productivity in rainfed situations) of different crop species and varieties using different water conservation techniques and fertilizer use strategies were established in Mozambique and Zimbabwe. Trials mostly followed the Mother-Baby technique with one complete replication of a 2 x 2 x 2 factorial trial in a village and several partial replications of this trial established on fields of nearby farmers. Results from the first year of trials have helped refine the focus of future field work in the project for the 2006/07 season. The total numbers of the crop varieties x soil fertility x water management technologies that will be evaluated with farmers in the 2006/07 season are 485, 108 and 47 for Zimbabwe, South Africa and Mozambique respectively. Training on crop varieties, seed production and water management techniques was provided to 86 collaborators from extension and farming communities of the three target countries

MA Mgonja and Sakile Kudita

Output Target B4: Diverse array of farmer/market preferred varieties and germplasm lines to which breeders can efficiently introgress resistances through MAB

Activity B4.1: Evaluate with farmer participation released and farmer varieties to identify target groundnut varieties for Marker Assisted Backcross (MAB) improvement

Milestone B4.1.1: 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 (ESM)

Evaluation of groundnut lines and Elite Varieties for Resistance to Rosette, ELS, Rust and Adaptability for different ESA agro-ecologies: Four nurseries were evaluated for different groundnut production constraints in ESA at the ICRISAT Chitedze Research Center in Malawi.

Details of performance of each set of trials for given constraints are reported. The following are top entries in the Elite Trials for the particular constraints tested:

- Under High Rosette disease pressure, the top three entries in the Elite (Spanish) Trial are: ICGV-SM 01515, ICGV-SM 99529 and ICGV-SM 01501 yield range 1.11 – 1.62 t ha^{-1} vs 0.51 t ha^{-1} for the check JL 24.
- Under High Rosette disease pressure, the top three entries in the Elite (Virginia) Trial are: ICGV-SM 88710, ICGV-SM 01710 and ICGV-SM 01708 yield range 1.22 – 1.78 t ha^{-1} vs 0.78 t ha^{-1} for the check CG 7.
- Under High ELS disease pressure, the top three entries in the Elite Trial are: ICGV-SM 95741, ICGV-SM 95713 and ICGV-SM 96678 yield range 0.76 – 1.18 t ha^{-1} vs 0.61 t ha^{-1} for the check JL 24.
- Rust and Late Leaf Spot were not in epidemic proportions – however the top three entries in the Elite (Spanish) were 86-87/175(b), 86-87/175-3, and 92R/70-4 yield range 3.00 – 3.39 t ha^{-1} vs 1.06 t ha^{-1} for the check JL 24.
- Similarly for the Elite Virginia Trial, top entries were ICGV 95346, RMP 12, and ICGV 90092 yield range 1.43 – 2.00 t ha^{-1} vs 1.24 t ha^{-1} for the check CG 7.
- Drought was not serious. Nevertheless the top three entries in the Elite (Spanish) were ICGV-SM 03535, ICGV-SM 03521, and ICGV-SM 03502 yield range 2.53 – 3.27 t ha^{-1} vs 1.60 t ha^{-1} for the check JL 24.

Three Regional Elite Nurseries (Spanish, Virginia and Valencia) were widely distributed across countries in ESA for evaluation and for selection of Elite varieties for national release in Malawi, Mozambique, Kenya, Tanzania, Zambia and Zimbabwe. The following are highlights of performance data for some of the varieties in reporting countries. Highlights of the Spanish type varietal trial results are reported here.

The Regional Elite Groundnut Variety Trial (Spanish):

- In Malawi, the top three varieties under high rosette disease pressure were ICGV-SM 01514, ICGV-SM 01506, ICGV-SM 01513, yielding 1.3 – 1.6 t ha-1 compared to the released resistant check ICG 12991 (0.7 t ha-1) or the standard check JL 24 (0.21 t ha-1), a yield advantage of over 600%. Under low disease pressure, the best three varieties were ICGV-SM 01513, ICGV-SM 01514, ICGV-SM 01502 yielding 1.8 – 2.5 t ha-1 this compared to the released resistant check ICG 12991 yield of 1.4 and the standard check JL 24 yield of 1.2 t ha-1 (a yield advantage 153 – 215%).
- In Tanzania the top three entries were ICGV-SM 01506, ICGV-SM 99574 and ICGV-SM 01504. However none of the entries were superior to the check JL 24. The apparent superiority was not expressed because there was no rosette disease pressure.
- In Zambia the top three entries were ICGV-SM 99589, ICGV-SM 96714 and ICGV-SM 99568 yielding 0.90 – 0.96 t ha-1 compared to the released check Katete (0.77 t ha-1).
- In Zimbabwe the top three entries were ICGV-SM 86068, ICGV-SM 01514 and ICGV-SM 96714 yielding 1.53 – 2.00 t ha-1 compared to the released check Nyanda (1.22 t ha-1)

With funding support obtained from the McKnight Foundation, the identified superior entries above will be subjected to farmer and market preference tests next season to further prioritize germplasm which will form the basis for a MAB for groundnut improvement in ESA region.

ES Monyo

Output Target B5: New backcross populations incorporating farmer/ market preferences and disease resistance and breeding populations with short duration for marginal drought prone areas [2010]

Activity B5.1: Develop groundnut mapping populations (F2/F3) incorporating farmer/market preferred varieties and known resistance sources for use with MAB

Milestone B5.1.1: At least one new breeding population each for GRD, ELS and rust resistance for ESA by 2009

Several seasons of evaluation of groundnut germplasm under artificial inoculations to create conditions conducive for resistance screening have identified several unique germplasm with enhanced levels of resistance. Simultaneous evaluation of the same under normal conditions have revealed few with high yield potential and preferred confectionary market traits.

The following are the proven sources for Groundnut Rosette Disease resistance: ICGV-SM 90704, ICGV-SM 94584, ICGV-SM 01501, proven sources for ELS; ICGV-SM 93555, ICGV-SM 95714 to be incorporated with farmer/market confectionary types – CG7, Chalimbana, ICGV-SM 87003, JL24, ICG 12991, ICGV 93437, Robut 33-1. Since the confectionary market is the fastest growing for groundnut demand from ESA, we have initiated a hybridization program that will combine resistance to the disease constraints with confectionary market traits. The F1s will be produced during the 2007 main season to generate F2/F3 mapping populations incorporating farmer/market preferred varieties and known resistance sources for use with MAB by 2009.

Activity B5.2: Phenotype segregating groundnut populations for GRD, ELS and/or rust with NARS in selected NARS hotspot locations

Milestone B5.2.1: At least 1 backcross population for each farmer preferred variety incorporating one or more sources of disease (GRD, ELS, rust) resistance or drought tolerance for use in marker assisted backcross improvement by 2009 (ESM, MO).

No report is due for 2006

Output 4C: Progress in knowledge and/or improved germplasm of nutritionally enhanced transgenic sorghum and bio-fortified transgenic events and non-transgenic germplasm with enhanced micronutrient levels available for evaluation with associated capacity building annually from 2009

Output Target C1: Transgenic sorghum breeding lines with increased levels of micronutrients to deliver Recommended Dietary Allowances (RDAs) of vitamins and amino acids developed for use in backcrossing to adapted varieties

Activity C1.1: Screen a core collection of sorghum germplasm to determine variability in morpho-agronomic and micronutrients traits

Milestone C.1.1: Variability for grain densities of Fe, Zn and β carotene determined in at least 200 accessions from at least two ESA countries by 2009

The World Health Organization (WHO) has widely recognized three micronutrients, Fe, Zn and beta carotene as the most limiting for human health. Essential amino acids such as lysine and methionine are also limiting in the diets of most people in ESA especially those whose diets are cereals such as sorghum. Commercial varieties that are available are very low in amino acids and vitamins. Bio-fortification is the process of breeding food crops that are rich in bio-available micronutrients. A number of initiatives by global alliances are in progress to bio-fortify the staple food crops. One such is the Grand Challenge for Global Health (GCGH) initiative that is supporting the project on African Bio-fortified Sorghum. One of the tasks in this project is to assess the natural variability for grain densities of Fe, Zn and β carotene among 450 landraces composed from the five ABS target countries. The landraces and varieties have been planted at Kiboko -Kenya during the 2006/07 season and after harvesting grain samples will be subjected to micronutrient compositional analyses to establish a baseline for the bio-fortification process.

MA Mgonja and SG Mwangi

Milestone C.1.2: Variability for morpho- agronomic traits determined by 2009

The 450 landraces and varieties composed from the five ABS target countries and being evaluated in milestone C1.1 will be assessed for variability of morpho-agronomic traits.

MA Mgonja and SG Mwangi

Milestone C.1.3: Heritability and correlations among micronutrient traits determined by 2009

The 450 materials planted at Kiboko-Kenya during the 2006/07 season under milestone C1.1 and assessed for micronutrients variability will provide data for assessing broad sense heritabilities and correlations among micronutrients to give a surrogate for the relationships of the micronutrients in the bio-fortified materials.

MA Mgonja and SG Mwangi

Milestone C.1.4: Correlations between morpho-agronomic and micronutrient traits determined by 2010

The 450 materials planted at Kiboko-Kenya during the 2006/07 season will provide data to allow establishment of correlations between morpho–agronomic and micronutrient traits.

MA Mgonja and SG Mwangi

Output Target C2. Regulatory and Biosafety aspects for approval of transgenic sorghum with enhanced micronutrient levels [2011]

Activity C2.1: Conduct non- transgenic baseline environmental and socio ecological research prior to introduction of transgenic micronutrient enhanced sorghum products for regulatory approval and deployment

Milestone C.2.1.1: Determinants of sorghum seed systems, variety information pathways and farmers' maintenance of variety purity established by 2009 in at least two ESA countries

A quantitative survey (structured & semi-questionnaire 200hh/district) was done in 2006 in three districts in Kenya where sorghum is an important crop and where a broad range of weedy/wild and cultivated sorghums co-exist. The objectives were:

- To determine biophysical, socio-economic and cultural factors influencing gene flow (pollen and seed mediated).
- Understand farmers' perception, knowledge and information pathways on sorghum varieties, seed systems, and agronomic practices
- Understand and get baseline information on human factors that influence on-farm gene flow and coping strategies e.g. variety purity maintenance

Data have been collected in the three districts of Western and Nyanza province and is in the process of analysis, and a report will be available in the 2007 archival report for project 4.

MA Mgonja and SG Mwangi

Milestone C.2.1.2: Farmers' knowledge on wild and weedy sorghum and implications on cultivated sorghum documented for at least 2 ESA countries by 2008

The analysis of the socio economic and cultural data collected from the three districts in Kenya and that which will be collected in South Africa will provide information on farmers' knowledge on wild and weedy sorghums and implications on cultivated sorghums and aspects of seed quality and variety identity or no identity preservation.

MA Mgonja and SG Mwangi

Activity C2.2: Understand the in situ dynamics of crop-to-wild and crop-to-weed genetic introgression in Kenya at the country scale

Milestones 2.2.1: Paper accepted on Sorghum crop-to-wild introgression rates in contrasted Kenyan agro-ecological regions (FS, SdV, DK, KARI, University of Free State, University of Hohenheim) 2008

During 2006 an extensive germplasm collection of cultivated landraces, cultivated-wild hybrids and wild sorghums was conducted in the Turkana, Western, Coastal and parts of Eastern provinces of Kenya. A total of 218 samples were collected. DNA, suitable for genotyping, has been isolated from all of these samples. 30 SSR markers were identified for diversity assessment and to date all samples have been genotyped with 12 of these markers. Additional collection trips are planned for 2007 to collect sorghum that mature in different seasons and to fill gaps that were not covered in the first collection. All additional samples will be added to the current 218 for genotyping to estimate the crop-wild geneflow.

F Sagnard, S de Villiers and DKiambi

Activity C2.3: Determine gene flow and outcrossing rates between cultivated, wild and weedy sorghum types and assess hybrid fitness in diverse ecologies using conventional and molecular markers

Milestone C.2.3.1: Molecular analytical laboratory equipped and 10 molecular markers identified for gene flow studies by 2007

The BioScience for Eastern and Central Africa (BECA) facilities were identified for the bulk of our studies. Other activities will be conducted in the Biotechnology laboratory, ICRISAT-India. There are over 100 SSR markers for sorghum that are publicly available and many more are being developed every month. SSR markers will be picked from the sorghum linkage map. SSR markers that are present/frequent in leading sorghum varieties in ESA but absent/rare in wild sorghums will be identified. Work on genotyping of leading sorghum varieties in ESA (22 varieties sent to CSIR) and wild sorghums was started at BECA, Nairobi in November 2006. Seeds from all the genotypes were germinated in trays and DNA extracted from10-day old seedlings using the CTAB method (Doyle and Doyle, 1987). A total of 24 sorghum SSR markers showing high polymorphism under the Generation Challenge Program Project are being evaluated. SSR markers that will show polymorphism between cultivated and wild/weedy sorghum will be identified. Other SSR markers will be tested later.

S Mwangi and MA Mgonja

Milestone C.2.3.2: Agro-ecosystem characterization and genetic sampling on the Intensive Study Site (South Meru District) completed and reported by 2007

During 2006, a Ph.D student was recruited in this project. He conducted a preliminary assessment of the chosen 8 x 8 km intensive study site to develop an appropriate sampling methodology for the further collections of cultivated and wild sorghum planned in this project. The aim was to identify the optimum number of farms that have to be sampled in order to acquire all the sorghum varieties grown in a particular target region and also to obtain some preliminary information on crop diversity and wild sorghum ecological distribution and identification criteria. This was done along an altitudinal gradient of 750 to 1200 masl and across 4 different language groups and it was concluded that at least 27 farms/sites at an interval of 20 m altitudinal difference need to be sampled in order to include all the varieties grown in the survey area. The presence of wild/weedy sorghums in close proximity to the cultivated counterpart seems to point to the occurrence of crop-wild geneflow. The planned studies on mating systems and geneflow will confirm both the historical and present occurrences. A more detailed survey is planned for 2007.

F Sagnard, S de Villiers and D Kiambi

Milestone C.2.3.3: Out crossing and gene flow between at least 5 cultivated and wild or weedy sorghum determined and reported by 2009

In situ introgression in natural habitat:
Seed samples of cultivated and weedy sorghums were collected from three districts (Busia, Teso, and Siaya) located in Western and Nyanza Provinces of Kenya in July 2006. The samples were planted at Kiboko, Kenya in November 2006 for morphological characterization. The samples will further be evaluated in the laboratory in 2007 using 10

SSR markers that are polymorphic between cultivated and wild sorghums. The frequencies of the SSR markers will be used as a measure of gene flow.

Determine the distance of pollen flow:
This activity is being conducted at two locations, Kenya and South Africa in 2006 and 2007. A well adapted variety will be planted in the center of the field in a 20 x 20 m plot as a source of pollen. From the center of the field in eight directions four rows of A-lines with similar maturity to the adapted variety will be sown. Seed set on the A-line was/will be recorded in a one-meter quadrant covering all the four rows at 10 meter-intervals up to a maximum of 100m. The presence of plants with seeds will be used to detect distance of pollen flow. The frequency of outcross seed will be used to determine the outcrossing percentage at various distances.

A trial was established at the Dominion farm in Yala, Nyanza Province, Kenya in April 2006. The pollen source was a locally adapted sorghum variety (Nahandavo) while the female rows were ms lines (ATX 623 and ICSA88006). Preliminary results indicate that mean outcrossing rates were high at short distance from the pollen source and the rate decreased as we move further from the pollen source; beyond 40 m, outcrossing rates were below 1%; outcrossing rates and pollen flow distance were high downwind than upwind. This trial will be repeated at the same site next season. A similar trial was planted at the University of Limpopo farm, South Africa on 28-29 November, 2006. The trial is being conducted in collaboration with the Department of Agriculture, Limpopo Province and the University of Limpopo. The pollen source was a locally adapted variety (SDS 6013) while the female rows are ms lines (A150, A8607, SDSA 27). Data is being collected during this 2007 by a University of Limpopo graduate student who intends to write a MSc thesis on this information

S Mwangi and MA Mgonja

Milestone C.2.3.4: Hybrid fitness determined between cultivated/wild and weedy sorghum types from at least two ESA countries by 2009

Hybrids produced from crop-wild sorghum crosses must persist in the wild if there is to be continued gene exchange in future. The possible generation of “superweeds” after fitness enhancing genes escape from transgenic crops to wild populations is a risk that is often discussed, but rarely studied (Halfhill et al, 2002). This study aims to evaluate the fitness of sorghum crop-wild hybrids for fitness parameters under field conditions.

This activity will be conducted at two sites in Kenya to evaluate the performance of cultivated, wild/weedy and crop-wild/weedy hybrid sorghums under field conditions.

Four cultivated varieties (IS 8593, KARI mtama 1, Gadam Hamam, Seredo) and two wild/weedy sorghum were planted in the crossing block at Kiboko in November 2006. Crossing between cultivated and wild/weedy sorghum will be made. The hybrids and parents will be evaluated for fitness and agronomic performance.

MA Mgonja and SG Mwangi

Milestone C.2.3.5: Fitness of F1, F2, BC1F1 crop-wild hybrids and their wild and cultivated parents evaluated in 2 experimental stations (Eastern and Coastal provinces) by 2008 (FS, SdV, DK + KARI + University of Hohenheim

Artificial, reciprocal crosses are planned between cultivated and wild sorghum varieties to assess the rate of crop-to-weed genetic introgression (and vice versa) and to determine the hybrid fitness resulting from such crosses. Two agro-ecological zones, low- and mid-elevation, have been selected and seed from the collection conducted in mid 2006 was planted at both locations for this purpose. A total of 64 crosses will be made (16 crosses in each of the 4 Sorghum growing areas) and these will be advanced to the F2 and BC1F1 stages in 2007.

F Sagnard, S de Villiers and D Kiambi

Milestone C.2.3.6: Documentation for the risk/safety assessments on the environment needed when actual GM will be presented for regulatory approval initiated by 2009

A document is being prepared on: The significance of gene-flow through pollen transfer in sorghum and implications at centre of diversity using other crops as examples. The document will be prepared in collaboration with the ABS Project regulatory affairs consultant, Dr Willy de Greef.

MA Mgonja and SG Mwangi

Output 4D: Technological options and knowledge to reduce aflatoxin contamination at different stages of the groundnut crop cycle developed and with associated capacity building measures disseminated annually to partner NARES, traders and processors in ESA for enhanced food and feed quality

MTP Output Target: Survey instrument for isolation of atoxigenic strains of Aspergillus flavus developed for ESA

Output Target D.1: Groundnut productivity, sale and income increased

Activity D1.1: Conduct participatory adaptive trials and demonstrations including promotion of systems for control and management of aflatoxin at different stages of the crop cycle
Milestone D1.1.2: Trainers available in quality on-farm seed production and maintenance, and pre-harvest and post harvest aflatoxin control measures implemented in at least 2 ESA NARS on an annual basis 2007- 2011

Training Programme for Field Officers on crop water productivity including soil/water conservation, seed production and harvesting technologies. Since aflatoxin contamination is conditioned by drought stress and poor post harvest handling of produce, the major tenets of this technology were emphasized in this training program offered through the Challenge Program Water for Food during 4-6 October 2006 at Polokwane, South Africa.

On-job training of field staff on field layout, data collection and data processing; and on-job training for front line staff in the Ministry of Agriculture from Ngabu (Malawi) on disease scoring and data collection were conducted.

Training of front line staff from Salima and Blantyre (Malawi) was organized on groundnut diseases and drought constraints affecting groundnut production.

ES Monyo

Activity D1.2: Conduct participatory adaptive trials and demonstrations including promotion of systems for control and management of aflatoxin at different stages of the crop cycle

Milestone D1.1.2: Trainers available in quality on-farm seed production and maintenance, and pre-harvest and post harvest aflatoxin control measures implemented in at least 2 ESA NARS in an annual basis 2007- 2011

Activity D1.2: Conduct field days, agricultural shows, & rural seed fairs with farmers, researchers, market players and processors to promote proven aflatoxin control practices

Milestone D1.2.1: Alternative seed production and distribution system implemented and documented by 2011

Programs for the dissemination of improved seed of ICRISAT mandate crops through promotion of alternative seed supply systems: Participated in developing training materials for on-farm seed production course held for field officers implementing CPWF-CP1 in Zimbabwe, 25–30 September and South Africa, 4–6 October. Forty trainees implementing program activities gained knowledge on seed production linked to on-farm demonstrations of crop water productivity technologies.

Discussions on basic revolving fund initiative was completed with Zimbabwe, South Africa and Mozambique. Agreements were reached to link CPWF-CP1 seed revolving fund with similar activities already under implementation through support from CIMMYT in Zimbabwe, and through USEBA in Mozambique. This activity will be linked with the community seed provision efforts through the Madzivandila Agricultural College which is operating with support from the Agricultural Research Council (ARC) of South Africa.

ES Monyo

Activity D2.1: Isolate atoxigenic strains of *Aspergillus flavus* from soils and develop protocols for multiplication

Milestone: D2.1.1: Survey of groundnut farms in Kenya and Malawi completed by 2007

Survey of groundnut farms: A survey of major peanut growing areas of Malawi and Kenya was carried out in 2005. A total of 162 (84 from Malawi and 82 from Kenya) soil samples were obtained for laboratory isolation and screening of *A. flavus* isolates for aflatoxin production. During this survey, a pod rot complex with obvious symptoms of *Sclerotium rolfsii* was identified as a major constraint to peanut production in both countries. Disease was most severe in fields around Karonga and Salima (eastern plains next to Lake Malawi) in Malawi and in Busia and Siaya districts in Kenya. Severity exceeded 35% of all pods in some fields in Karonga area while a field incidence >25% was recorded in one field in Busia district. Of the farmers interviewed, 59% and 65% in Malawi and Kenya, respectively, were not aware of 'mold' damage or aflatoxin problems of peanuts. A protocol for soil isolation and quantification of *Aspergillus* spp. section *Flavi* was developed and tested in Nairobi. Screening of isolates of *A. flavus* for aflatoxin production was completed and at least six atoxigenic strains identified.

RB Jones

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

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

MTP Output Targets 2006
Sorghum
New genetic variability introgressed and new derivates less susceptible to shoot fly and grain mold hybrid parents available to partners

Pearl Millet
At least 9 each of male-sterile and restorer lines and more than 800 trait-specific and downy mildew (DM) resistant improved breeding lines developed and disseminated

Pigeonpea
Knowledge on hybrid seed production in pigeonpea published and disseminated globally for the first time

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)

Race-specific trait-based B-lines: To diversify hybrid parents for high yield, large grain and other 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 different traits while maintaining desired maturity and grain yield. Promising F_4 progenies with maintainer reaction are being converted into A-lines with A_1 and A_2 CMS systems. They are in the various stages (BC_2 to BC_9) of conversion. The B-lines that were completely converted into male-sterile lines and stabilized were evaluated in replicated yield trials. The results are as under.

Preliminary B-line trial (PBT): Maintainers (B-lines) of five newly developed male-sterile lines with A_1 CMS system and 17 newly developed lines with A_2 CMS system were evaluated along with two checks in preliminary B-line trial during the 2006 rainy season. For grain yield, two B-lines of the A_1 CMS system – SP 18847 (4.6 t ha^{-1}), SP 18845 (4.5 t ha^{-1}) and 5 B-lines of the A_2 CMS system – SP 19255 (5.2 t ha^{-1}), SP 19207-1 (4.9 t ha^{-1}), SP 19257 (4.9 t ha^{-1}), SP 19213 (4.6 t ha^{-1}), SP 19251 (4.6 t ha^{-1})] were significantly superior to the check 296 B (3.6 t ha^{-1}). The panicle grain mold rating showed that one B-line of the A_2 CMS system SP 19257 (1.7) and two B-lines of the A_1 CMS system SP 18847 (2.0) and SP 18845 (2.0) were superior (where 1 = no grain mold infection and 5 = >75% infection) compared to the susceptible check 296B (3.0).

Advanced B-line trial (ABT): An ABT consisting of 21 high-yielding B-lines selected from the evaluation of Preliminary B-line trial during the 2005 postrainy season was conducted during the 2006 rainy season. Fifteen of the test B-lines with grain yield ranging from 3.8 to 5.0 t ha^{-1} were on par with the check 296B (4.7 t ha^{-1}). The most promising among them include SP 2863, SP 2305, SP 2781 and SP 2385.

BVS Reddy

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 grain 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 only possess moderate resistance levels.

1. A total of 26 F_6 progenies developed from the crosses involving grain mold resistant B-lines, grain mold resistant landraces and high-yielding B-lines were evaluated in a preliminary screening trial for GMR and also testcrossed to identify maintainer lines for conversion into male-sterile lines during the 2006 rainy season. The data from the screening nursery is awaited. From the breeding nursery, 35 F_7s tolerant to grain mold (PGMR $\leq$5) and the desirable agronomic traits were produced and harvested along with their testcrosses for assessing their maintainer/restorer reaction

2. In an advanced screening trial for GMR, a total of 72 F_6 progenies developed from the crosses of grain mold resistant landraces, high-yielding B-lines and grain mold resistant breeding lines were evaluated during the 2006 rainy season. These progenies along with their testcrosses on known sources of A_1 and A_2 CMS systems-based male-sterile lines were also evaluated in a separate nursery in the breeding block during the 2006 rainy season. The results from screening trial are awaited. A total of nine lines with GMR (PGMR $\leq$5) and maintainer reaction were selected from the breeding block nursery. They included two white grain lines and seven red grain lines.

Shoot fly resistance: Shoot fly is one of the major biotic constraints in both rainy and postrainy seasons. Considering that the available seed parents bred for shoot fly resistance (SFR) possess only moderate resistance levels and grain yield potential, efforts are underway to develop and diversify seed parents for SFR.

1. A total of 110 rainy season-adapted F_7 progenies (which included 55 progenies with testcrosses and the remaining 55 yet to be testcrossed) derived from crosses involving shoot fly resistant B-lines and high-yielding B-lines were advanced with selection in 2005 postrainy season. Based on maintainer/restorer reaction, 36 testcrosses and parents were selected for backcrossing. However, backcrossing could be carried out only on 32 parents (BC_1s). The remaining four testcrosses and parents will be advanced and testcrossed along with the evaluation and continuation of backcrossing of 32 BC_1s (as set 1) in the 2006 rainy season. The 55 F_7 progenies (which were yet to be testcrossed) were testcrossed onto known A_1 and A_2 CMS systems-based male-sterile lines in 2005 postrainy season. Based on visual assessment of agronomic aspects, 39 testcrosses and parents were selected for assessing their maintainer/restorer reaction (as set 2) in the 2006 rainy season.
    - The set 1 (32 BC_1s and 4 testcrosses parents) and set 2 (39 testcrosses parents) were screened for SFR in a screening block and also evaluated in a breeding block for a conversion program in the 2006 rainy season. In set 1, the deadhearts ranged from 40 to 69%. The resistant control (IS 18551) had 59% deadhearts and susceptible control (296 B) had 80% deadhearts. Corresponding BC_1s in breeding block which showed below 60% deadhearts in screening block were further backcrossed and a total of 20 BC_2s (8 on A_1, 8 on A_2 and 4 A_1 and A_2) were selected.

    - In set 2, 35 testcrosses and parents and four parents to be testcrossed were screened for SFR in screening block and also evaluated in breeding block for conversion program in the 2006 rainy season. Due to very poor germination and crop establishment, data on deadhearts could not be recorded in the screening block. However, in the breeding block, based on agronomic performance, 10 testcross progenies with maintainer reaction (BC_1s) (6 on A_1 and 4 on A_1 and A_2) were selected for screening for shoot fly resistance.

BVS Reddy, RPThakur and HCSharma

Advanced B-lines resistant to sorghum shoot fly: In an advanced B-line trial, 21 lines along with three checks viz., 296B, ICSB 52, and IS 14384 were evaluated for resistance to shoot fly, *Atherigona soccata,* during the 2006 postrainy season in a randomized complete block design with three replications. Data were recorded on leaf glossiness score (1 = highly glossy, and 5 = non-glossy) and shoot fly deadhearts at 14 and 18 days after seedling emergence. The leaf glossy score ranged from 4.7 to 5.0 in the advanced B-lines compared to 5.0 in 296B and 2.7 in

IS 14384. At 18 days after seedling emergence, deadheart incidence ranged from 50.3 to 85.9% in the seed parents compared to 33.7% in IS 14384 and 75.7% in 296B.

HC Sharma and BVS Reddy

Milestone 5A.1.1.3: Five new high-yielding and large grain male-sterile lines in diverse backgrounds developed (BVSR/HDU, 2009)

High-yielding, large seeded male-sterile lines: A total of 631 F_3s derived from high-yielding B-line × B-line crosses were evaluated during the 2006 rainy season and 509 F_4s were produced. Similarly, from the evaluation of 104 F_3s derived from high-yielding B-line × B-line crosses during the 2005 postrainy season, a total of 20 F_4s were produced. These were evaluated during the 2006 rainy season and simultaneously testcrossed onto A_1-based male-sterile line. From 20 F_4s, 47 F_5s were produced.

A total of 896 F_5 progenies derived from the crosses involving high-yielding B-lines, brown-midrib lines and sweet sorghum B-lines were advanced with selection and testcrossed onto A_1-based male-sterile line, and the resulting 654 F_6 seed and the testcrosses were harvested.

From 46 F_2s (derived from crosses involving postrainy season-adapted varieties, landraces and high-yielding B-lines) evaluated during the 2005 postrainy season, 123 F_3s were produced. Similarly, from 81 F_3s (derived from crosses involving postrainy season-adapted varieties, landraces and high-yielding B-lines) evaluated during the 2005 postrainy season, 62 F_4s were produced during the 2006 postrainy season.

Large grain postrainy season-adapted germplasm lines: A total of 98 highly lustrous and 128 medium-lustrous germplasm lines were planted in two separate trials during the 2005 postrainy season. Due to severe midge attack, the data on grain traits could not be recorded. Hence, during the late 2005 postrainy season, 98 highly lustrous germplasm lines were re-planted for use in a crossing program. Depending on the synchrony of flowering, 67 germplasm lines were crossed with elite advanced breeding progenies with maintainer reaction and established high-yielding B-lines. The 129 F_1s, so generated were planted in the 2006 postrainy season.

In order to diversify the hybrid parental lines adapted to the postrainy season for grain yield and grain size, 11 germplasm lines with large grain (>4.5 g 100^{-1}) IS 30654, IS 30684, IS 30651, IS 30719, IS 19928, IS 19938, IS 35050, IS 36554, IS 36557, IS 30683 and IS 30678 were crossed with elite advanced breeding lines having maintainer reaction. A total of 57 F_1s were made and advanced during the 2006 rainy season. The F_2s are being evaluated during the 2006 postrainy season.

BVS Reddy 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 (BVSR/RPT/HCS, 2010)

Shoot fly resistance: In a program to develop new male-sterile lines resistant to shoot fly, several shoot fly-resistant germplasm lines (new lines that were not used before) were crossed with high-yielding established B-lines. The 126 F_2s derived from these crosses were evaluated during the 2006 rainy season and 240 F_3s were produced which are being evaluated in the 2006 postrainy season.

In another program to develop shoot fly resistant male-sterile lines in diverse genetic backgrounds, 31 F_1s were made 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, shoot fly resistant germplasm line and stem borer resistant line. The F_1s are being advanced.

BVS Reddy and HC Sharma

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)

While several single-QTL introgression lines were generated in 2007 in these two recurrent parent genetic backgrounds, and screening to assess the efficacy of the introgressed shoot fly resistance QTLs was initiated (see Milestone 5A.2.1.6), no further funds are available to continue application of this work [pyramiding the effective shoot fly resistance QTLs (once these had been confirmed) in these genetic backgrounds and then developing male-sterile lines from the QTL introgression lines].

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 F_4 lines developed for resistance to each of grain mold and shoot fly (BVSR/RPT/HCS/RS, 2008)

Grain mold resistance: A total of 200 F_4s derived from the crosses between grain mold resistant B-lines and high-yielding lines were screened for GMR [panicle grain mold rating (PGMR) score taken on 1 to 9 scale where 1 = no mold or <10% and 9 = >90%] in a nursery during the 2006 rainy season. These were also evaluated and testcrossed onto A_1 and A_2 CMS systems in breeding nursery during the 2006 rainy season. The data from the screening nursery are awaited. From the breeding nursery, 51 F_5s tolerant to grain mold (PGMR ≤5) and desirable agronomic traits were produced and harvested along with their testcrosses for assessing their maintainer/restorer reaction.

BVS Reddy and RP Thakur

Shoot fly resistance

Shoot fly resistant maintainers: 12 F_5s derived from the crosses between shoot fly resistant maintainer lines and high-yielding breeding lines (as set 3) were screened for shoot fly resistance in screening block and also evaluated in breeding block for testcrossing in the 2006 rainy season. The deadhearts ranged from 41 to 88%. The resistant control – IS 18551 showed 20% and susceptible control – 296 B showed 87% deadhearts. Corresponding 47 progenies with testcrosses (22 on A_1, 25 on A_2) in the breeding block which showed below 65% deadhearts were selected for continuing the conversion program.

Shoot fly resistant maintainers (postrainy season): In the 2005 postrainy season, 80 F_4s, 174 F_5s, and 17 F_6s with postrainy season adaptation were screened for SFR in a screening block and also advanced in breeding block for testcrossing onto A_1 and A_2 CMS systems-based male-sterile lines. Based on deadheart % (below 57%) in the screening block, 203 F_5 progenies (with 28 testcrosses on A_2, 118 testcrosses on A_1 and A_2 and 57 yet to be testcrossed) from 80 F_4s; 166 F_6 progenies (14 testcrosses on A_2, 101 testcrosses on A_1, A_2 and 51 to be testcrossed) from 174 F_5s; and 20 F_7 progenies (11 testcrosses on A_1 and A_2 and 9 to be testcrossed) from 17 F_6s were produced. These testcross parents along with 27 stabilized B-lines are being evaluated as four separate sets for SFR in screening and breeding blocks in the 2006 postrainy season.

BVS Reddy and HC Sharma

Restorer lines evaluated for resistance to sorghum shoot fly, *Atherigona soccata:* Over 50 F_6 lines were screened for resistance to sorghum shoot fly, *A. soccata* during the 2006 rainy season along with resistant (IS 18551) and susceptible (296B) checks in a randomised complete block design with three replications. Deadheart formation ranged from 10.7 to 58.4%, and 11 lines suffered <25% deadheart incidence compared to 14.1% in the resistant check, IS 18551, and 43.9% in the susceptible check, 296B. The lines 31249, 31242, 31274, and 31292-1 suffered 10.7 to 12.4% deadhearts, and were the most promising.

HC Sharma and BVS Reddy

Pest-resistant nurseries supplied to NARS: A set of 30 lines identified to be resistant to insects (shoot fly, stem borer, aphids, midge and head bugs) were assembled in the form of international pest resistance screening nursery, and ten sets of it were distributed to NARS on request. The material was planted in a randomized complete block design, and there were three replications. Data were recorded on leaf feeding and deadheart formation for stem borer under artificial infestation. Lines SBRIL 66175, SFRIL 65111, SFRIL 65136, SFRIL 65146, SFRIL 65153, SFRIL 65222, SFRIL 65273, SFRIL 65278, and ICSV 700 suffered <20% deadhearts and a leaf damage rating of <5.0 compared to 8.8% in IS 18551, 2.7% in IS 2205, 43.0% in Malisor 84-7, and 17.8% in Swarna. The same material was also screened for resistance to shoot fly, *A. soccata* under natural infestation. Data were recorded on leaf glossiness and deadheart incidence at 14 days after seedling emergence. The lines SFRIL 65108, SFRIL 65136,

SFRIL 651151, SFRIL 65278, IS 2205, ICSV 705, and PS 30710 showed <40% deadhearts and a glossy score of <1.7 compared to 23.9% deadhearts in IS 18551 (glossy score 1.0) and 66.8% deadhearts in Swarna (glossy score 5.0).

HC Sharma and BVS Reddy

Milestone 5A.2.1.2: Two F_6 RIL populations (300 lines each) developed for mapping grain mold resistance (CTH/BVSR/SPD/RPT/RS, 2008)

No progress yet

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_5 populations (i) IS 23599 × AKMS 14B (350 RILs) and (ii) IS 25017 × KR 188 (350 RILs) and their parents are being advanced to next generation (F_6) during the 2006 postrainy season.

BVS Reddy

Milestone 5A.2.1.4: Putative QTL for stem borer resistance and its components based on RIL from two crosses identified (HCS/CTH/SPD, 2009)

Mapping population evaluated for resistance to stem borer: To identify molecular markers associated with resistance to the spotted stem borer, *Chilo partellus*, the mapping population of 270 lines from the cross IS 18551 × 296B was evaluated for resistance under artificial infestation in a randomized complete block design with three replications. Data were recorded on leaf feeding, deadheart formation, leaf glossiness, days to panicle initiation, recovery resistance, agronomic score, and grain yield. Leaf damage rating (DR) varied from 4.5 to 7.8. Deadheart formation ranged from 31.3 to 97.9% in the mapping population, 44.2% in the resistant check - IS 2205, and 56.7% in the susceptible check ICSV 1. The 296B showed 68.2% deadheart formation compared to 63.2% in IS 18551. Leaf glossiness score varied from 1.0 to 5.0 in the mapping population as compared to 1.3 in IS 2205 – the resistant check, and 4.7 in the susceptible check - ICSV 1. Leaf glossiness score was 5.0 in 296B and 1.0 in IS 18551.

The mapping population, PB 15881-3 × ICSV 745, was evaluated for resistance to sorghum midge during the 2005/06 postrainy season. There were three replications in a balanced alpha design. Data were recorded on midge damage (1 = <10% spikelets with midge damage, and 9 = >80% spikelets with midge damage). Midge damage in the mapping population ranged from 2.0 to 9.0 compared to 1.0 in the resistance check, ICSV 197, and 7.7 in the susceptible check, Swarna. The resistant (ICSV 745) and the susceptible parents (PB 15881-3) suffered a midge DR of 2.0 and 6.3, respectively. Data analysis to identify QTLs associated with resistance to these insects is in progress.

HC Sharma, BVS Reddy and CT Hash

Milestone 5A.2.1.5: Comparative mapping of QTL for stem borer resistance in sorghum and maize completed (HCS/SPD/DH/CTH, 2009)

A total of 272 and 363 progenies (along with their parents) of sorghum $F_{6:10}$ RIL mapping populations derived from crosses [ICSV 745 (susceptible to stem borer) × PB 15220-1 (resistant to stem borer)] and [ICSV 745 × PB 15881-3 (resistant to stem borer)], respectively, were sown during the 2006/07 postrainy season for seed multiplication. These populations will be screened for stem borer resistance during the 2007 and 2008 rainy seasons. DNA extraction for these populations has been completed.

HC Sharma, SP Deshpande, D Hoisington and CT Hash

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)

To be reported in 2007

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)

To be reported subsequently

Output target 5A.3: 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.3.1: Understanding host-pathogen-environment interaction in grain mold complex.

Milestone 5A.3.1.1: Major grain mold pathogens in sorghum growing states in India identified and their distribution in relation to weather factors determined (RPT/RS, 2007)

Weather variables and grain mold pathogens: We conducted a Sorghum Grain Mold Resistance Stability Nursery (SGMRSN) under the ICAR (AICSIP)-ICRISAT partnership project at five AICSIP centers Coimbatore, Dharwad, Parbhani, Palem and Patancheru. The SGMRSN 2006 consisted of 50 entries (14 from NRCS and 36 from ICRISAT). In addition to grain mold severity, data on weather variables (temperature, relative humidity and rainfall) were also collected from these centers. Molded grain samples from these locations will be assayed for the presence of various mold fungi and their frequency determined. From these and earlier data sets of the past four years, the relationship between weather variables and frequency of mold pathogens at different locations will be determined.

RP Thakur and Rajan Sharma

Milestone 5A.3.1.2: Mycotoxin-producing isolates of Fusarium species associated with grain mold identified and characterized and genetic resistance in relation to other major pathogens determined (2009)

Genetic resistance to sorghum grain mold: Identification of advanced sorghum breeding lines and germplasm accessions with improved level of grain mold resistance has been a major focus towards developing grain mold-resistant hybrids. During 2006, a number of sorghum lines were screened in the glasshouse against individual pathogens and in the grain mold nursery at ICRISAT, Patancheru, against general mold fungi.

Grain mold resistance in hybrid parental lines: Twenty sorghum genotypes [12 B-lines, 6 R-lines and 2 susceptible checks (CSH 9 and SPV 104)] were screened against three prominent pathogenic fungi, *Fusarium verticillioides* (high fumonisins-producing strain), *Curvularia lunata* and *Alternaria alternata* under glasshouse conditions. The experiment was conducted in a randomized complete block design (RCBD) with 20 genotypes × 3 fungi × 3 replications with 10 plants per replication. Panicles were inoculated at >80% flowering stage with conidial suspensions of individual fungi and exposed to wetness for 48 h after inoculation. As the visual mold infection was not clearly evident, we measured grain mold colonization at hard dough (HD), physiological maturity (PM) and on threshed grain (TG) using the blotter method and 50 grains per replication at each grain development stage. In general grain colonization by different fungi at HD was low and varied from 0 to 38%. However, grain colonization at PM and of TG was quite variable for sorghum genotypes × pathogen combinations.

Grain colonization by *F. verticillioides* varied from 1 to 40% on test genotypes compared to 8–32% on susceptible controls. Similarly, grain colonization by *C. lunata* varied from 11 to 92% on test genotypes compared to 51–95% on susceptible controls, while that by *A. alternata* varied from 0 to 85% on test genotypes compared to 1–6% on susceptible controls. Sorghum genotypes with resistance to single and multiple pathogens were identified. Four genotypes (ICSB 352-5, ICSB 402-3, ICSB 370-2 and ICSR 89013-2) were resistant to *F. verticillioides* (0–9% colonization); three genotypes (ICSB 402-3, ICSB 402-1-2 and SGMR 40-1-2-3) to *C. lunata* (7–17% colonization) and five genotypes (ICSB 402-3, ICSB 402-1-2, IS 41397-3, SPV 462-3, SP 72519-1-3) to *A. alternata* (0–5% colonization). Of these, only one genotype (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*. This information would be useful for breeding grain mold resistant hybrids and for studies on genetics and mechanism of resistance.

Grain mold resistance in selections from B- and R-lines: Ninety-seven grain mold-resistant single plant selections (33 from 14 B-lines and 64 from 24 R-lines from the 2005 screen) along with 4 resistant and 4 susceptible checks were evaluated to confirm their resistance. The experiment was conducted in a RCBD with 2 replications, 1 row of 2 m long/replication. 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, where 1 = no mold infection and 9 >75% molded grains on a panicle. The mean grain mold scores on test genotypes ranged from 2.0 to 7.8 compared to 1.0–2.0 score on resistant checks (IS 14384, IS 8545 and IS 25017) and 8.8–9.0 score on the susceptible checks (CSH 9, CSH 16, Bulk Y and SPV 104). Results indicated that 50 selections (23 from 8 B-lines and 27 from 10 R-lines) were resistant (≤3.0 score). Some of these selections have been utilized in developing test hybrids.

Grain mold resistance in sorghum germplasm: One hundred fifty-six germplasm lines reported as resistant to grain mold during 1985–87 along with two resistant and one susceptible checks were screened to find the stability of resistance under field conditions. These were evaluated unreplicated with 2 rows of 2 m per entry. Sprinkler irrigation was provided twice a day for 30 min. each on rain-free days from flowering to physiological maturity. The visual grain mold scores were recorded at physiological maturity (PM). The grain mold scores of the test lines varied from 1 to 7 compared to 1.0 to 2.0 on resistant checks (IS 14384 and IS 25017) and 9.0 on the susceptible check (SPV 104). Of the 156 lines, 19 (IS 3413, IS 8848, IS 13885, IS 14375, IS 14380, IS 14384, IS 14385, IS 14387, IS 14390, IS 13756, IS 21599, IS 24995, is 24989, IS 24996, IS 25038, IS 25075, IS 25084, IS 25100 and IS 25105) were highly resistant (1.0 score); 134 resistant (1.1 to 3.0 score) and 3 moderately resistant (3.1–5.0 score). Some of the highly resistant germplasm lines from the 19 identified above having desirable agronomic traits would be useful in breeding program to develop grain mold resistant hybrid parents.

Grain mold resistance in *zerazera* selections: Thirty-two selections from two *zerazera* conversion lines (IS 18758C and IS 30469C) and two susceptible checks were evaluated for grain mold resistance. The 34 entries were grown in a RCBD with 2 replications, 1 row of 2 m per replication. The sprinkler irrigation was provided twice a day for 30 min. each on rain-free days from flowering to physiological maturity. The grain mold scores were recorded at physiological maturity (PM). Five (from IS 18758C) of the 32 selections were moderately resistant (3.4 to 4.3 score), while the remaining were susceptible (>6.0 scores). These five resistant selections are early maturing with medium height and white grain and thus could be utilized in grain mold resistance breeding.

RP Thakur and Rajan Sharma

Milestone 5A.3.1.3: Relative contributions of host and environmental factors in mold development assessed (RPT/RS/BVSR, 2010)

Host and environmental factors in relation to mold development: In the 2006 grain mold nursery, we evaluated 156 germplasm lines reported as resistant (during 1985–87) to confirm their resistance under changed environment and screening procedure. These lines originate from different countries of Africa and possess diverse morphological traits (such as panicle shape and size, grain color, glumes color and glumes coverage of grains) and agronomic traits (plant height and days to flowering). In addition to grain mold severity, we obtained data on the above morphological and agronomic traits. From these and other data sets from diverse breeding lines collected during the past years we plan to determine the relative contributions of host and environmental factors to grain mold development.

RP Thakur, Rajan Sharma and BVS Reddy

Activity 5A.3.2: Develop screening techniques and investigate host genotype - natural enemy interactions, resistance mechanisms and genetics of insect pest resistance

Milestone 5A.3.2.1: Insect–host genotype - natural enemy interactions, and mechanisms of resistance and their inheritance studied in sorghum (HCS/BVSR, 2009)

Physico-chemical mechanisms of resistance to sorghum shoot fly: Fifteen lines comprising of shoot fly-resistant and -susceptible types were evaluated for resistance to *Atherigona soccata* under no-choice, dual-choice and multi-choice conditions in the field and glasshouse. There were three replications in a randomized complete block design. Data were recorded on shoot fly oviposition, deadheart formation, recovery resistance, leaf glossiness score, trichome density, insect survival and development, and fecundity. There were 5.11 eggs per 10 plants in IS 2146 to

19.55 eggs on ICSV 112, and 16.49 in case of Swarna. Deadheart incidence ranged from 55.85 in IS 2312 to 99.2% in Swarna, compared to 78.3% deadhearts in the resistant check, IS 18551. Under dual-choice conditions, the genotypes IS 1054, IS 2146, IS 18551, IS 4664, and SFCR 125 showed non-preference for oviposition as compared to the susceptible check, Swarna. Antibiosis in terms of success of the neonate larvae to establish on the plants and cause a deadheart was observed in case of IS 1054, IS 1057, IS 18551, IS 2312, IS 4664, IS 2205, SFCR 125, SFCR 151, and ICSV 700. The leaf glossiness score varied from 1.0 to 5.0. Genotypes showing less susceptibility to shoot fly were trichomed and had a leaf glossiness score of <3.0. Genotypes IS 18551, IS 4664, IS 2312, SFCR 151, and ICSV 700 showed some adverse effects on the survival and development of *A. soccata*.

Transplanting and clipping of leaves at 15 days after seedling emergence resulted in a significant reduction in deadheart formation in the shoot-fly resistant genotypes, but did not result in better recovery or overall resistance and agronomic performance at maturity. Some of these lines also showed resistance to stem borer, *Chilo partellus* and the sugarcane aphid, *Melanaphis sacchari* during the postrainy season. Biochemical analysis of the plant samples for essential minerals, nutritional quality, and secondary metabolites in relation to expression of resistance to sorghum shoot fly is in progress.

HC Sharma

Milestone 5A.3.2.2: Techniques to evaluate sorghums for resistance to sugarcane aphid and shoot bug developed, and sources of resistance identified in sorghum (HCS, 2009)

Improved breeding lines resistant to sugarcane aphids: Thirty-five sorghum lines comprising of improved breeding lines and germplasm accessions were screened for resistance to sugarcane aphid, *Melanaphis sacchari* during the 2006 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) and agronomic performance (1 = good, and 5 = poor). The lines 61011, 61523, 61588, 61592, 61596, DJ 6514, ICSB 12, ICSB 88017, ICSV 197, ICSV 700, ICSV 745, and IS 40620 showed an aphid damage rating of <2.5 compared to 3.5 in the resistant check TAM 428, 5.5 in CK 60B, and 6.5 in Swarna. Of these, the lines 61011, 61523, 61588, ICSB 88017, and ICSV 745 were also desirable agronomically, and can be used in sorghum improvement program to develop cultivars for resistance to *M. sacchari.*

HC Sharma and BVS Reddy

Output target 5A.4: Information on association between CMS and agronomic traits, and between molecular diversity and yield heterosis in sorghum (2009)

Activity 5A.4.1: Evaluation of iso-cytoplasmic hybrids for grain yield and agronomic traits

Milestone 5A.4.1.1: Twelve hybrids with four diverse CMS systems compared for agronomic traits and resistance to shoot fly and grain mold (BVSR/RPT/RS/HCS, 2009)

CMS effect on grain yield and resistance to grain mold and shoot fly: 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 a 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 cytoplasms. 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_2 A_3 and A_4 CMS system in comparison to the widely used A_1 CMS system.

Isonuclear alloplasmic A-lines with A_1, A_2, A_3 and A_4 (G), A_4 (M) and A_4 (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 M 35-1-19) to generate 72 hybrids in 2005 postrainy season. These 72 hybrids were evaluated for grain yield and other traits during the 2006 rainy season in split-split-plot design with three replications using R-lines as main plots, genetic backgrounds of A-lines as sub-plots and cytoplasm in 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 and shoot fly in screening blocks.

Grain yield and other traits: There were significant differences amongst female nuclear genotypes for days to 50% flowering, plant height and grain yield but the differences were non-significant amongst R-lines. Similarly, non-significant mean squares due to A × R-line interaction indicated that hybrids do not differ significantly for their *sca* effects for grain yield. Cytoplasm *per se* appeared to have significant influence on the expression of hybrids for plant height and grain yield, as evident from significant mean squares due to cytoplasm. It is important to note that first-order interaction of cytoplasm with nuclear genetic background of A-lines (for all traits) or R-lines (for grain yield) and second-order interaction with A-line and R-lines (for all traits) towards variation of iso-nuclear hybrids was significant, suggesting significant but variable influence of cytoplasm for grain yield, depending on the genetic background.

The comparison of A_1, A_2, A_3, A_4 (M), A_4 (G) and A_4 (VZM) cytoplasms-based hybrids indicated that A_4 (M) cytoplasm-based crosses were significantly earlier to flower compared to those based on A_3 and A_4 (VZM) cytoplasms (though only by a day, which has no practical significance). A_2 cytoplasm-based hybrids were significantly taller compared to A_3, A_4 (M), A_4 (G) and A_4 (VZM) cytoplasm-based hybrids by 6 to 9 cm, (which again has no practical significance). A_1, A_2, A_3, A_4 (M), A_4 (G) cytoplasm based hybrids were significantly superior to A_4 (VZM) cytoplasm-based hybrids (by 1.0 t ha^{-1}) and were comparable among themselves.

Thus, the comparable grain yield potential of A_2, A_3, A_4 (M), A_4 (G) cytoplasms-based hybrids in similar maturity and plant height backgrounds suggests the usefulness of A_2, A_3, A_4 (M), A_4 (G) cytoplasms for diversifying the cytoplasmic and nuclear genetic base of sorghum hybrid parents.

BVS Reddy

Grain mold resistance: There were significant differences amongst A-lines (nuclear genotype) and R-lines for PGMR score, suggesting considerable differences among the parents for responses to grain mold. Significant mean squares due to cytoplasm *per se* as for PGMR indicated that cytoplasms showed differential responses to grain mold. The significant mean squares due to interaction of cytoplasms with A-lines and R-lines and A × R-lines interaction suggested that the effect of cytoplasms was significantly influenced by the genetic backgrounds of both female and male parents.

The comparison of A_1, A_2, A_3, A_4 (M), A_4 (G) and A_4 (VZM) cytoplasms-based hybrids indicated that A_1, A_2, A_3, and A_4 (VZM) cytoplasms-based hybrids were relatively less susceptible to grain mold than those based on A_4 (M) and A_4 (G) cytoplasms. However, when mean PGMR scores of different cytoplasms-based hybrids were examined, there were seldom any differences in their responses to grain mold.

BVS Reddy and RP Thakur

Male-sterility-inducing cytoplasm *vs* normal fertile cytoplasm: Two sets of 36 (A × R) hybrids in iso-nuclear alloplasmic backgrounds (36 in A_1 and 36 in A_2) were made by crossing iso-nuclear, alloplasmic A_1 and A_2 system A-lines in 12 nuclear genetic backgrounds with three dual R-lines. The male-fertile counterparts of the 12 male-sterile lines (B-lines) were emasculated and crossed with the same three dual R-lines and obtained 36 B × R crosses. The two sets of 36 A × R and one set of 36 B × R crosses were evaluated at ICRISAT, Patancheru during the 2006 rainy season in split-split-plot design using three replications by using R-lines in the main plots, A-lines as sub-plots and cytoplasms as sub-sub-plots. The 12 A-lines and their B-lines were evaluated in a separate trial using randomized complete block design with three replications. Sufficient care was taken for adequate supply of pollen grains to A-lines for meaningful comparison of yield performance of A-lines *vs.* B-lines.

There were significant differences amongst A-/B-lines (nuclear genotype) and R-lines for plant height and grain yield justifying the selection of the hybrid parents (A/B- and R-lines). Similarly, significant mean squares due to A-/B- × R-lines interaction indicate that hybrids differed significantly for their *sca* effects for grain yield. Cytoplasm *per se* appeared to have significant influence on the expression of hybrids for plant height as evident from significant mean squares due to cytoplasm. It is important to note that first-order interaction of cytoplasm with nuclear genetic background of A-lines (for grain yield) or R-lines (for all the traits) and second-order interaction with A-line and R-lines (for grain yield) towards variation of iso-nuclear hybrids were also significant, suggesting that the cytoplasm was influenced by the genetic backgrounds of both male and female parents.

The comparison of A × R and B × R crosses (in both A_1 and A_2 backgrounds) indicated that while A × R (both A_1 and A_2) crosses were significantly early (by 1 day in both A_1 and A_2 backgrounds for days to 50% flowering) and significantly taller (by 0.2 m in A_1 and by 0.2 m in A_2 backgrounds), B × R crosses manifested higher grain yield (by 0.1 t ha^{-1} than A_1 and by 0.2 t ha^{-1} than A_2 cytoplasm) when average performance of A_1 and A_2-based A × R and B × R hybrids as separate groups was considered.

Significant cytoplasmic effects were observed for all the traits when individual nuclear genetic backgrounds of A × R (both A_1 and A_2) and B × R crosses were examined. Significant cytoplasm effects were detected in some of the nuclear genetic backgrounds for all the traits. While A × R crosses, besides being early, were taller compared to those of B × R crosses in a majority of nuclear genetic backgrounds, the reverse was true for grain yield. These results were not in conformity with those reported earlier, wherein A × R crosses were significantly superior to B × R crosses for grain yield suggesting the need for repetition of the trials for onfirming these results.

BVS Reddy

Shoot fly resistance: The F_1 hybrids based on different male-sterile cytoplasms were tested for resistance to sorghum shoot fly, *A. soccata* under field conditions using interlard fishmeal technique. Seventy-two hybrids and 12 restorers were tested for resistance to shoot fly under natural infestation. There were three replications in a randomized complete block design. Data on shoot fly deadhearts were recorded at 18 days after seedling emergence, when the differences between the resistant and susceptible checks were maximum. Shoot fly deadhearts ranged from 40.0 to 100.0% in the hybrids, and it was 28.8% in IS 18551, 84.8% in 296B, and 81.2% in CSH 16. Hybrids based on $ICSA_4M$ were less susceptible than those based on other cytoplasms.

In another trial, 26 hybrids, 10 B-lines, and 10 restorers along with resistant, IS 18551 and susceptible, CSH 16 checks were evaluated for resistance to shoot fly, *A. soccata*. There were three replications in a randomized complete block design. Data on shoot fly deadhearts was recorded at 18 days after seedling emergence, when the differences between the resistant and susceptible checks were maximum. Shoot fly deadhearts ranged from 32.2 to 78.4% in the hybrids, and it was 46.1% in IS 18551, and 91.1% in CSH 16. Hybrids based on ICSA 425 and ICSA 452 were less susceptible than those based on ICSA 455, indicating the potential of using these lines for producing shoot fly resistant hybrids.

HC Sharma and BVS Reddy

Activity 5A.4.2: Assessing the relationship between molecular diversity of parental and yield heterosis

Milestone 5A.4.2.1: Relationship between parental molecular diversity and hybrid heterosis assessed (CTH/SPD/BVSR, 2009)

To be reported subsequently

Output target 5A.5: High-yielding and good combining sorghum hybrid parents developed for postrainy season adaptation (2009)

Activity 5A.5.1: Developing high-yielding and good combining sorghum hybrid parents for postrainy season adaptation

Milestone 5A.5.1.1: Five each of high-yielding and good combining sorghum male-sterile lines and restorer lines for postrainy season developed (BVSR, 2009)

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.

A total of 44 postrainy season-adapted F_6 progenies were evaluated and testcrossed onto A_1–male-sterile line. From these, 34 F_7 progenies were produced and their testcrosses were harvested. The selected progenies flowered in 76–86 days and had a plant height range of 1.3 to 2.1 m.

In another nursery, 384 F_5s derived form B × B crosses were evaluated and testcrossed onto A_1–male-sterile line producing 359 F_6 seed and harvested their testcrosses. The selected progenies flowered in 75−100 days and had a plant height range of 1.1 to 2.0 m.

In yet another nursery 93 F_5 progenies were evaluated producing 78 F_6 progenies and their testcrosses onto A_1–male-sterile line during the 2005 postrainy season. The selected progenies flowered in 75−95 days and had plant height ranging from 1.5 to 2.5 m. From 140 postrainy season-adapted F_4 progenies evaluated, 241 F_5s were produced. The selected progenies flowered in 74–97 days and had a plant height range of 1.1 to 2.5 m.

Combining ability of hybrid parents: To identify the best combiners among the postrainy season-adapted B-lines and restorers and to identify good hybrid combinations, eight postrainy season-adapted B-lines (ICSB 6, ICSB 14, ICSB 51, ICSB 52, ICSB 215, ICSB 297, ICSB 592, ICSB 675) were crossed to eight postrainy season -based R-lines (IS 4504-1, M 35-1-19-1, M 35-1-69-1, M 35-1-16-1, M 35-1-25-1, BP Ent 14, SP 7521, SP 7523) in a Line × Tester mating design to produce 64 hybrids. These 64 hybrids were evaluated along with a hybrid check CSH 15R in a RCBD design during the 2005 postrainy season.

Significant differences were observed among the lines and testers for days to 50% flowering, plant height, stay-green score, lodging score, grain yield and 100-grain weight. Significant line × tester interaction mean squares for grain yield, stay-green score and lodging score suggested the involvement of dominance and/or epistatic gene action. While ICSB 297 and ICSB 592 among the A-lines and M 35-1-19-1 and M 35-1-69-1 among the R-lines were good general combiners for grain yield, ICSB 6 and ICSB 52 among the A-lines and IS 4504-1 and Ent 14 among the R-lines were good general combiners for grain size. The hybrids, ICSA 215 × M 35-1-19-1 and ICSA 51 × IS 4504-1 were good specific combiners for grain yield.

R-line development: From the seed parent development program for postrainy season adaptation, the advanced progenies with R-reaction were evaluated.

A total of 605 F_3s derived from high-yielding R × R crosses were evaluated, and 140 F_4 seeds were produced during the 2005 postrainy season, and evaluated during the 2006 rainy season to produce 36 F_5s. Days to 50% flowering in the selected progenies ranged from 69 to 75 days and plant height ranged from 1.3 to 2.7m.

From the 53 postrainy season-adapted F_5 progenies (variety × variety crosses) evaluated during the 2005 postrainy season, 31 F_6 progenies were produced and their testcrosses were harvested. The selected progenies flowered in 77 - 87 days and had a plant height range of 1.0 to 1.8 m.

From the 63 (F_7) advanced selections, derived from postrainy season-adapted large- grain and high-yielding variety × variety crosses, 25 advanced progenies were produced and evaluated in a trial during the 2006 postrainy season.

Restorer lines trial (RLT-2005R): A trial was constituted with 40 advanced breeding lines showing restorer reaction. The material in the trial includes the lines developed from the crosses involving postrainy season-adapted varieties (M 35-1, SPV 1359) and advanced breeding lines and the selections from M 35-1 bulk for evaluation for grain yield and other desirable traits in a randomized complete block design with three replications along with the checks Moulee and M 35-1. Compared to the check M 35-1 (2.1 t ha^{-1}), 31 R-lines with a grain yield range of 3.1 to 4.7 t ha^{-1} performed significantly better for grain yield and seven of these were significantly superior to the check Moulee (3.2 t ha^{-1}). The luster score among these 31 lines varied from 1.0 to 2.7 (M 35-1: 1.0, Moulee: 1.0), while the grain size varied from 1.7 to 2.6 g 100^{-1} grains (M 35-1: 2.1g 100^{-1} grains, Moulee: 2.4g 100^{-1} grains).

BVS Reddy

Output target 5A.6: High-yielding dual-purpose foliar disease resistant forage/sweet sorghum hybrid parents (2009)

Activity 5A.6.1: Developing dual-purpose foliar disease resistant forage/sweet sorghum hybrid parents

Milestone 5A.6.1.1: 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 2005 postrainy season. Results of these trials are given below.

Sweet sorghum B-line trial: Based on the performance of sweet sorghum B-lines evaluated during the 2005 rainy season, a total of 30 B-lines were selected and evaluated along with the checks NSSH 104 and SSV 84 in the 2005 postrainy season. ICSB 73 with 0.9 t ha^{-1} sugar yield performed significantly better than the best check NSSH 104 (0.74 t ha^{-1}) for sugar yield based on Brix reading and juice yield, while ICSB 324 (0.7 t ha^{-1}), ICSB 652 & 401 (0.6 t ha^{-1}) and ICSB 24001 (0.5 t ha^{-1}) were significantly better than SSV 84 (0.3 t ha^{-1}). The performance of the lines for other traits is presented in Table 1.

Sweet sorghum advanced B-line trial (SSABLT, 2006K): Based on the performance of B-lines in sweet sorghum B-line trial in 2004 postrainy season, 2005 rainy and postrainy seasons, PPV (Protection of Plant Varieties) trials in 2004 rainy and postrainy seasons, PPV trials in 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. Three B-lines, ICSB 729 (3.3 t ha^{-1}), ICSB 722 (3.1 t ha^{-1}), ICSB 321 (3.0 t ha^{-1}) were on par with the check SSV 84 (2.7 t ha^{-1}) for sugar yield. Among these, ICSB 722 (14 t ha^{-1}) was significantly better than the check 296 B (10.9 t ha^{-1}) for grain yield, while the rest of them were on par with 296 B, except ICSB 321. The performance of these lines for other traits is given in Table 2.

Table 1. Performance of selected sweet sorghum B-lines (at maturity stage) - 2005 postrainy season at ICRISAT, Patancheru

B-line	Days to 50% flowering	Plant height (m)	Cane yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix reading at maturity	Sugar yield based on Brix reading and juice yield (t ha^{-1})
ICSB 73	75	1.5	13.8	5.7	16.7	0.9
ICSB 324	75	1.5	12.0	3.7	19.0	0.7
ICSB 652	75	1.3	11.1	3.3	16.7	0.6
ICSB 401	75	1.4	12.9	4.2	13.0	0.6
ICSB 24001	75	1.5	13.2	4.4	11.7	0.5
NSSH 104 (Check)	73	1.5	13.3	5.3	13.3	0.7
SSV 84 (Check)	70	1.4	9.0	2.7	16.3	0.4
Mean	75	1.2	6.9	2.1	12.0	0.3
CV (%)	3.9	15.0	21.9	22.3	22.4	29.4
CD (5%)	3.96	0.30	2.5	0.74	4.36	0.13

Table 2. Performance of selected sweet sorghum B-lines (at maturity stage) - 2006 rainy season at ICRISAT, Patancheru

B-line	Days to 50% flowering	Plant height (m)	Cane yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix reading at maturity	Sugar yield based on Brix reading and juice yield (t ha^{-1})	Grain yield (t ha^{-1})
ICSB 729	77	2.2	49.5	23.4	14.7	3.3	10.9
ICSB 722	75	2.2	41.5	20.5	15.2	3.1	14.0
ICSB 321	78	2.3	40.6	18.0	17.5	3.0	7.9
SSV 84 (Check)	82	2.9	45.7	18.6	18.2	3.3	3.0
296 B (Check)	69	1.5	12.1	2.7	8.3	0.5	10.9
Mean	67	1.6	21.5	9.2	12.9	1.2	11.4
CV (%)	1.69	8.20	12.5	21.11	9.33	30.3	11.84
CD (5%)	1.82	0.22	4.36	3.13	1.94	0.41	2.17

Sweet sorghum male-sterile line development: A total of 10 crosses were made involving lines with high Brix (SSV 84, ICSV 700) and low Brix (ISIAP DORADO, BTx 623), and high-yielding lines (ICSB 52 and ICSB 101). The 10 F_1s are planted in 2006 postrainy season for advancement.

Milestone: 5A.6.1.2: Six new high-yielding sweet sorghum restorers identified (BVSR/HDU, 2008)

Sweet sorghum varietal and restorers trial: Based on the performance of sweet sorghum varieties and restorers in the trial during the 2005 rainy season, 45 lines were selected and evaluated along with the checks SSV 74, SSV 84 and NSSH 104. Compared to the sugar yield in checks (SSV 74: 1.2 t ha^{-1}, SSV 84: 0.5 t ha^{-1} and NSSH 104: 1.1 t ha^{-1}), 14 varieties were significantly superior (1.67 to 3.0 t ha^{-1}). Some of the lines had high brix reading but poor juice yield. They include IS 21991 (21.2), SP 4511-3 (21.0) and SP 4511-2 (20.0). These lines will be used in crossing program. The performance of the top five high-yielding lines for sugar yield is given in Table 3.

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Table 3. Performance of selected sweet sorghum varieties/restorers (at maturity stage) - 2005 postrainy season at ICRISAT, Patancheru

Variety/restorer	Days to 50% flowering	Plant height (m)	Cane yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix reading at maturity	Sugar yield based on Brix reading and juice yield (t ha^{-1})
SP 4484-2	94	2.0	36.3	18.08	16.0	3.0
SP 4487-3	95	2.1	35.3	14.0	17.7	2.4
SP 4504-2	95	2.2	33.3	14.0	17.3	2.3
SP 4482-2	94	2.2	29.8	13.2	18.7	2.3
SP 4482-1	95	2.0	33.4	13.4	17.0	2.2
SSV 84 (Check)	86	1.5	10.7	2.7	17.3	0.5
NSSH 104 (Check)	86	2.0	19.5	7.6	14.2	1.1
SSV 74 (Check)	88	2.1	18.9	6.5	18.7	1.2
Mean	94	1.9	20.6	7.6	16.2	1.2
CV (%)	1.9	7.9	27.8	23.5	12.0	28.9
CD (5%)	2.85	0.24	9.28	2.90	3.15	0.57

Output target 5A.7: Stay-green QTLs associated with improved fodder quality introgressed into elite sorghum hybrid parents and their potential utility assessed (2010)

Activity 5A.7.1: Mapping and introgression of stay-green QTL into elite parental lines, and assessment of their effects on hybrid performance

Milestone 5A.7.1.1: Assessment of near-isogenic BC_3F_3 and BC_4F_3 stay-green QTL introgression lines completed in R 16 and ISIAP Dorado backgrounds (2010)

Evaluation of early-generation R 16 stay-green QTL introgression lines: We completed two years of field evaluation of the initial (BC_1 and BC_2) stay-green (non-senescent) introgression lines with 1–4 QTL in the background of the Indian postrainy season sorghum variety R 16. The primary objectives of the evaluation were to (1) assess the phenotypic expression of various stay-green QTL under postrainy season conditions, when available (stored) soil moisture is limited, and stress-induced crop senescence is the norm, and (2) assess the effects of stay-green on the ability to maintain grain yield in moisture-deficit environments and on the ruminant nutritional quality of stover. There were differences in the senescence patterns of the various QTL introgression lines, but in general, across all test environments, the average percent green leaf area (% GLA) of all the introgression lines fell between the values of the two parents. Even though a number of the introgression lines contained many of the putative stay-green QTL from B 35, none demonstrated the same degree of stay-green as did B 35, especially in the latter part of the grain-filling period. Nevertheless, the data indicated that the transfer of various stay-green QTL from B 35 to R 16 was successful in improving the stay-green character of the latter, in both stress and non-stress conditions.

There were significant, linear and positive (although somewhat variable) relationships of the ability to maintain normal green leaf area, and normal grain filling with 100-grain mass (r^2 = 0.32 and 0.56) and grain yield (r^2 = 0.34

and 0.76) in two of the three dryland environments. Only in the most severely stressed environment, where virtually all of the lines senesced, were the relationships non-significant. Thus, backcrossing the non-senescence trait into a generally senescent lines should result in improved grain filling and, therefore, improved grain yield in most dryland, postrainy season environments, at least when introgressed into genetic background as senescent as R 16. An attempt to explain differences in various ruminant nutritional quality traits of the stover of the R 16 QTL introgression lines by differences in stay-green indicated no quantitative relationship in four of the five environments. Only in the 2005–2006 supplementally irrigated environment, where the leaf senescence was generally less than that in the other environments, was there a modest relationship between % GLA and stover N% and % GLA and stover digestibility. This was despite six of the introgression lines having a significantly higher mean N% than R 16 across all environments. It may be that a stronger expression of stay-green will be needed in the introgression lines to significantly improved the stover quality.

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Milestone 5A.7.1.2: Stay-green QTL mapping of E 36-1 confirmed based on phenotypic assessment of two F_6 RIL populations genotyped with DArT, SSR, and CISP-SNP markers (CTH/SS/SPD/VV, 2010)

Progress to be reported in subsequent years

Milestone 5A.7.1.3: 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)

Progress to be reported in subsequent years

Milestone 5A.7.1.4: Initial evaluation of animal performance on near-isogenic hybrids differing in allelic composition at two stay-green QTLs completed (CTH/SPD/MB/BVSR, 2010)

Progress to be reported in subsequent years

Output target 5A.8: Commercialization of sorghum grains and impact of improved germplasm enhanced

Activity 5A.8.1: Strengthen research and development partnerships, and technology exchange

Milestone 5A.8.1.1: Hybrid parents (>50) and other breeding materials (>100) supplied to NARS and their impact assessed (BVSR/Sorghum Team—annual)

Seed producers' sorghum hybrid trial (SPSHT): 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 constituted and coordinated in rainy and postrainy seasons by ICRISAT as one of the activities of the ICRISAT-Private sector Sorghum Hybrids Parents Research Consortium. Under this activity, SPSHT during the 2006 rainy season with 14 entries was conducted at five consortium members' locations (Biostadt, Aurangabad; MHseeds, Jalna; Emergent Genetics, Hyderabad; Kanchan Ganga and Nuziveedu Seeds (2 locations), Hyderabad; and Tulasi Seeds, Guntur) who volunteered to conduct the trial as well as at ICRISAT, Patancheru. Due to incessant rains at crop maturity stage in Guntur, the grain yields were so low that the trial was lost. Data from the other five locations were analyzed and reports distributed to all consortium members who contributed the hybrids. The results showed that the mean grain yield of MLSH 60 was on par with the check SPH 1342, with 10% larger grains. Among the others, three hybrids viz., BSH 10, BSH 33, and BSH 31 were comparable to the check CSH 16 for grain size.

Sorghum scientists' field days: Field visits were arranged for public and private sector scientists. Sorghum scientists' field day was organized at ICRISAT, Patancheru on 28-29 September 2006 for public and private sector scientists for selection of the breeding materials and to get feedback on the ICRISAT-supplied breeding material. A total of 46 scientists (28 public sector and 18 private sector scientists) participated in the field day and selected 971 distinct lines. A total of 2460 sorghum seed samples (1377 samples including 459 samples of designated hybrid seed parents selected by 13 public sector scientists and 1083 samples including 365 samples of designated hybrid seed parents selected by 11 private sector scientists) were supplied. The selected progenies/lines (where sufficient seed is not available) are being multiplied in 2006–07 postrainy season to supply them in February 2007.

Seed supplies: A total of 1768 seed samples of hybrid parents/breeding lines were sent to 16 countries. India received 1375 samples followed by Mexico 95 samples. Of the 1375 seed samples to India, 651 were sent to public sector scientists, and 682 to private sector scientists. Seed in bulk quantities (278 kg) of six high-yielding/released cultivars was supplied to 42 farmers. We also supplied 150 kg seed of NTJ 2 and 15 kg seed of SSV 84 to Rusni Distilleries, Hyderabad, for seed multiplication in farmers' fields.

Partnerships with NARS, networks and regional fora strengthened: A salinity-tolerant hybrid trial (consisting of 30 hybrids) and a salinity-tolerant varietal trial (consisting of 29 varieties) were sent for evaluation at ARS, Gangavathi, Karnataka in saline soils. Seed of 12 salinity-tolerant varieties was multiplied and sent to Central Rice Research Institute, Cuttack, India for evaluation in saline soils in farmers' fields.

Seed of sweet sorghum varieties and hybrids was multiplied and sent to National Research Centre for Sorghum (NRCS), Hyderabad, India, for testing at the All India Co-ordinated Sorghum Improvement Project (AICSIP) locations in the 2006 rainy season. Three varieties were tested in advanced sweet sorghum varietal trial (ASSVT); one variety in initial sweet sorghum varietal trial (ISSVT); one hybrid in advanced sweet sorghum hybrid trial (ASSHT) and four hybrids in initial sweet sorghum hybrid trial (ISSHT).

A sorghum grain mold resistance stability nursery (SGMRSN) consisting of 33 ICRISAT-bred grain mold resistant hybrid parents and 22 NARS-bred hybrid parents in elite genetic backgrounds along with the five checks was constituted and sent for evaluation at Akola, Dharwad, Parbhani, Palem and Coimbatore for GMR in the 2006 rainy season. This enabled NARS scientists to select grain mold-resistant hybrid parents suitable for their locations for further use in grain mold resistance improvement programs or for direct utilization in hybrid development.

The use of the breeding materials by private sector scientists: The utilization of ICRISAT-bred sorghum hybrid parents by private sector scientists was assessed through a good mix of formal (structured questionnaires and one-to-one dialogue) and informal means. A social scientist and a sorghum breeder from ICRISAT met the representatives of 16 private sector organizations who are members of sorghum hybrid parents' research consortium.

The preliminary findings indicated that a total of 15 hybrids are being marketed by 10 private sector organizations, with each having marketed at least one hybrid. All of these 15 hybrids involve various proportions of ICRISAT-bred germplasm in at least one of the hybrid parents. Two hybrids have been developed by directly using ICRISAT-bred A- and R-lines; two hybrids have been developed by directly using ICRISAT-bred R-lines; four hybrids involve both parents with 25–50% ICRISAT-bred improved germplasm content; six hybrids involve both the parents with 50–75% ICRISAT-bred hybrid parents' content. One hybrid has been developed by directly using ICRISAT-bred A-line and R-line with 50% ICRISAT-bred improved germplasm. These preliminary results clearly indicate that sorghum hybrids being marketed by private sector organizations are largely based on ICRISAT-bred improved hybrid parents, particularly the A-lines.

Technical information and documents developed and dissemination: The results of SPSHT-2005 rainy season trial were summarized, report prepared and distributed to all the members of sorghum hybrid parents research consortium who contributed hybrids for the trial. Prepared the reports of (a) ICAR-ICRISAT partnership projects and distributed to all the concerned at All India Coordinated Sorghum Improvement Project (AICSIP) group meeting held at Marathwada Agricultural University (MAU), Parbhani during May 2006. Further, two information bulletins on 1) Sorghum grain mold and 2) population improvement in sorghum, book chapter on "Sorghum Hybrid Parents Research at ICRISAT–Strategies and Impacts" were prepared and distributed to all sorghum scientists. Also, some of the ICRISAT-bred sorghum hybrid parents were characterized as per DUS test guidelines of Indian Council of Agricultural Research and published as "Characterization of ICRISAT-bred Sorghum Hybrid Parents" in a special issue of International Sorghum and Millets Newsletter in 2006.

Farmers' preferred cultivars identified: The seed of eight sorghum cultivars preferred by farmers (CSV 15, PVK 801, ICSV 93046, ICSR 93034, SPV 422, NTJ 2, SPV 1411 and SPV 1359) in IGNRM system was multiplied and distributed for evaluation in the watersheds (Sujala and TATA projects) for assessing farmer-preferred varieties of various crops. The most preferred varieties by farmers were PVK 801 for rainy season and SPV 1411 for the postrainy season.

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Milestone 5A.8.1.2: Ten sorghum scientists trained biannually (BVSR/Sorghum Team—alternate year)

A learning program on "Sorghum Hybrid Parents and Hybrid Research and Development" is planned to be conducted from 6 to 17 February 2007. About 25 sorghum scientists from both public and private sector organizations from Asia and Africa and Latin America are expected to participate in the program.

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Milestone 5A.8.1.3: Two thousand farmers adopt improved sorghum cultivars and crop production practices in India, China and Thailand (ASA/ChRR/BVSR/PPR/ CLLG/FW, 2007)

The project titled "Enhancing the utilization of sorghum and pearl millet grains in poultry feed to improve the livelihoods of the small-scale farmers in Asia" funded by CFC–FAO is operational since 2005. The project aims at (i) development of effective coalition of all stakeholders (groups of small-scale sorghum and pearl millet farmers, poultry and feed production farmers, private sector, NGOs, etc.) in order to improve crop productivity and enhance skills in harvesting, bulking, storage and handling practices of grain, (ii) identifying the constraints in sorghum and pearl millet production and to provide information on improved production (aims at packages and seeds of improved cultivars by involving private seed companies), (iii) strengthening input supply chain system (fertilizers, pesticides, seeds of improved varieties, credit facility etc.) for sorghum and pearl millet production and output supply chains to stimulate the use of these crops as raw material for commercial poultry feed production, (iv) develop linkages with other input dealers for credit, seeds, fertilizer, etc., by organizing farmers into groups for effective input delivery mechanisms, and (v) to link farmer groups with poultry feed manufacturing companies and poultry producers to enable the farmers to sell the grain to feed manufacturers for use in manufacturing poultry feed.

As a part of basic requirement for implementation of the project, two clusters in Andhra Pradesh, three clusters in Maharashtra, and one cluster each in China and Thailand have been identified. A total of 10 partners were identified as coalition partners to support the project activities that includes research institutes, state agricultural universities, Krishi Vignana Kendras (KVKs), and private sector companies. The farmers' associations have been formed and necessary support has been extended to these partners. The farmers were trained in the use of improved production technologies, grain bulking, grading and improved grain storage technologies for sorghum and pearl millet.

The project interventions enabled farmers to realize enhanced sorghum productivity in Andhra Pradesh clusters by 70–90% and in Maharashtra clusters by 20–30%; and pearl millet productivity by 90–110% in Andhra Pradesh and Maharashtra clusters through improved production practices. Storage structures have been constructed in the clusters in India through farmers' participatory approach and being used by cluster farmers for bulking their sorghum and pearl millet grains.

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Milestone 5A.8.1.4: 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)

One of the major activities of the CFC-FAO-ICRISAT project is to link the farmers cultivating sorghum and pearl millet with the processors. Thus, the reasons for distress sale of the produce immediately after the crop harvest to the commission agents/ middlemen in the local market or to the money lenders were studied. The study of the marketing systems in the project area indicated that this distress sale of the farm produce is due to one or more of the following reasons:

- Immediate cash needs of the farmers for family expenses such as education/health/ family functions
- Repayment of loans borrowed from private money lenders
- Lack of storage space for keeping the produce without deterioration in grain quality
- Lack of market intelligence/non-availability of market information
- Difficulties of transport of small quantum of produce to market

The project is promoting the utilization of sorghum and pearl millet for poultry feed in India, China and Thailand. Efforts to link small and marginal farmers to the processors (poultry feed manufacturers and other industrial users) through bulk storage and marketing is being promoted. To overcome the above constraints, the project has facilitated the farmers to get organized into Farmers Associations though participatory approaches and helped them in constructing the storage structures and drier sheds. Panicle driers were also installed in all the cluster villages which were helpful in drying the produce to the required moisture levels.

The farmers have been trained in various aspects of bulk marketing such as aggregation of the produce, scientific storage, godown management, grading of the produce, negotiating the sale price with feed manufacturers and poultry producers, etc.

Bulking and bulk marketing aims at storing the farmers produce in a godown over a period for gaining better market price. Grains were dried to established moisture levels, which could extend their shelf life and prevent the losses from pest and diseases. The drier installed in the clusters were useful in ensuring the drying of the produce. The farmers were able to realize a better price, through enhanced bargaining power, minimization of middlemen charges/exploitation, increased involvement of the farmers and improved market intelligence that helped in expanded market.

In 2006, farmers (association) were linked with the poultry feed manufacturers. During the current season farmers bulked more than 225 t of sorghum and stored in the godowns constructed under the project. The stored produce was sold to M/s Janaki Feeds Private Limited @ Rs 6000−6250 per t from the project villages in the clusters of Maharashtra and Andhra Pradesh. Thus, farmers realized an additional income of Rs 750−1250 per t as compared to the market prices, which were about Rs 5250 per t.

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)

Male-sterile line (A-line) development: Development and dissemination of up to nine morphologically diverse A-lines with high grain yield potential and downy mildew resistance annually continues to be making a direct contribution to strengthening the hybrid development programs in the public and the private sector. In 2006, nine 2006-series A-lines (2 A_1 cytoplasm and 7 A_4 cytoplasm) with 40−54 days to flowering, 13−23 cm panicle length and 7.4−13.8 g 1000-seed mass were developed for dissemination. Under high disease pressure in the glasshouse (more than 95% DM incidence in susceptible check 843B), four of these were highly resistant (0−10% DM incidence) to all the five diverse pathotypes (Jodhpur, Jalna, Jamnagar, Durgapura and Patancheru), another four were resistant to at least four of the five pathotypes, and one was resistant to three pathotypes (Jodhpur, Durgapura and Jamnagar). Conversion of 34 elite maintainers of A_1 CMS system into A_4-system A-lines was completed. The sixth and final backcross of these maintainers was completed to convert them into A_5-system A-lines. Seed of these A_4- and A_5-system A-lines is now available for dissemination. About 210 B-lines and their counterpart backcross (BC) progenies were evaluated and backcrossed for further advancement for A-line breeding. Of these, 172 B-lines and their BC_5–BC_{10} progenies (67 A_1, 97 A_4 and 48 A_5) were selected for further advancement. Another set of 165 B-lines and their early generation BC progenies (61A_1, 92A_4 and 84A_5) were evaluated of which 120 B-lines were selected for advancing to BC_2-BC_4. First backcross was made with 11 B-lines, of which 5 B-lines and their backcross progenies (1 A_1, 5 A_4 and 5 A_5) were selected for further backcrossing.

In a continuing effort of pyramiding DM resistance genes into ICMB 89111, all the 260 BC_5F_4 progenies were screened against Patancheru pathotype under heavy disease pressure (>95% DM incidence in susceptible check 81B) under glasshouse condition. About 70 resistant progenies (d_2 dwarf) with <5% DM incidence were evaluated during the 2006 rainy season, of which 12 were selected based on visual assessment for phenotypic resemblance to

ICMB 89111. Seven of the selected progenies flowered in 54 days and 2 in 55 days, while 3 flowered in 56 days (ICMB 89111-P_2 flowered in 54 days and ICMB 89111 flowered in 52 days).

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Restorer line (R-line) development: A restorer development and dissemination strategy, similar to that followed for A-lines, was initiated in 2006. Nine 2006-series R-lines (5 A_1 cytoplasm and 4 A_4 cytoplasm) with 46–60 days to flowering and 11–30 cm panicle length were developed for dissemination. Under high disease pressure in the green house (>95% DM incidence in susceptible check 843B), eight of these were highly resistant (0–10% DM incidence) to four of the five diverse pathotypes (Durgapura, Jodhpur, Jalna, Jamnagar and Patancheru) and one was resistant to two pathotypes (Durgapura and Jodhpur). About 60 A_4 restorer progenies (S_7-S_{12}) were evaluated during the rainy season, of which 42 were selected with 33 of these flowering in 46–60 days (checks ICMR 356 flowered in 49 days and ICMP 451 in 52 days).

In 2005 rainy season, 62 potential A_4 R-lines had been identified based on the limited testcross evaluation of their fertility restoration. These were crossed on 2 A_1 and 6 A_4 male-sterile lines. Results showed that 44 of these were A_1 restorers, 32 were A_4 restorers (fertility restoration proven on at least on 4–6 A-lines), and 24 were dual-restorers. Of these, 25 lines flowered in 49–55 days, and 37 lines flowered in 56–62 days (ICMP 451 flowered in 52 days). All the 62 potential restorers were tested for resistance to Durgapura and Jalna pathotypes, of which 34% were highly resistant (<10% incidence) to Durgapura pathotype and 16% were highly resistant to Jalna pathotype under high disease pressure (susceptible checks ICMP 451 and 834B had >95% DM incidence against both pathotypes). About 80 additional potential restorer progenies were crossed on both $81A_1$ and $81A_4$ during the postrainy season and the resultant testcross nursery was evaluated for fertility restoration during the rainy season. Of these, 50 showed fertility reaction on $81A_1$, 29 on $81A_4$, and 11 on both $81A_1$ and $81A_4$.

Restorer line yield trial: Two dual-purpose restorer progenies with large morphological differences for panicle length/girth and seed size, but expected to have high gain yield were compared with three commercial varieties (ICTP 8203, WC-C 75 and Raj 171) and a commercial hybrid (ICMH 356) for grain yield in a 5-replication yield trial at Patancheru during the 2006 rainy season. Raj 171 was the highest-yielding variety (1533 kg ha^{-1} grain yield) with 49 days to flower, 170 cm plant height, 22 cm panicle length, 1.5 panicles $plant^{-1}$ and 8.4 g of 1000 seed mass. Both inbred lines had 70% of the grain yield of Raj 171, flowered in 52 days, with tillering ability similar to Raj 171, and 30–35 cm shorter height. While the MC 94-derived inbred line had 2 cm longer panicle than Raj 171 and 9.3 g of 1000-seed mass, the long panicle line had 39 cm long panicle and smaller seed (6.7 g 1000-seed mass).

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Milestone 5A.1.1.2: Seed parents and restorer parents adapted to arid zone developed (KNR/RB/FRB/RPT/RS, 2010)

Hybrid parents adapted to western Rajasthan: The Sehgal Foundation provided 3-year funding support in the year 2002 to increase the emphasis on breeding seed parents specifically adapted to arid Rajasthan. During the third year of the project, restorer line breeding was also included in this project. Although the project ended in 2004, the materials generated from this project have been carried forward.

Seed parent progenies: Two types of materials were generated that have been further evaluated and advanced: (i) progenies derived from ICRISAT-CAZRI B-composite (ICCZBC) that was constituted from a set of diallel crosses, and (ii) progenies derived by pedigree breeding in some of the most promising B × B crosses in the above diallel. About 275 S_4 progenies derived from ICCZBC were evaluated during the 2006 rainy season, of which 86 were selected, with 34 of these flowering in 41–50 days and 48 flowering in 51–55 days (checks 843B flowered in 44 days and 81B in 56 days). Another 268 S_3 progenies were evaluated in the summer drought nursery, of which 152 were selected based on the visual agronomic evaluation. Of these, 21 progenies flowered in 46–50 days and 91 flowered in 51–55 days (checks 843B flowered in 47 days and 842B in 55 days).

We also evaluated 191 F_7/F_8 progenies derived from B × B crosses during the 2006 rainy season, of which 90 were selected, with 23 of these flowering in 41–50 days and 53 flowering in 51–55 days (checks ICMB 94555 flowered in 48 days, 842B in 46 days and 843B in 44 days). About 100 F_5 progenies derived from these crosses were also evaluated during the summer season in drought nursery, of which 54 were selected. Of these, 20 flowered in 51–55 days and 34 flowered in 56–60 days (checks ICMB 93111 flowered in 58 days, ICMB 95444 in 55 days and ICMB 93333 in 57 days).

Restorer parent progenies: About 100 progenies (S_6–S_9) were evaluated in the drought nursery during the summer season, of which 40 were selected based on visual assessment for agronomic traits. Of these, 18 flowered in 46–50 days (checks RIB 3135-18 flowered 55 days and H 77/833-2 in 52 days). In addition, 13 progenies (S_8–S_{10}) were evaluated during rainy season and all flowered in 46–55 days (check H 77/833-2 flowered in 44 days).

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Evaluation of hybrid parents progenies: We continued the evaluation in western Rajasthan of four sets of breeding materials bred specifically for adaptation to the arid zone. These included 48 lines from the Mandor Restorer Composite, 46 lines from the ICRISAT-CAZRI Maintainer Composite, 24 crosses of adapted B-lines and 11 restorer populations. We evaluated testcrosses of these lines (made with arid zone-adapted testers) to assess their hybrid potential for grain and stover yields under arid zone conditions. Because of the high degree of inherent variability in rainfall in the arid zone, years differ significantly in the timing and severity of the inevitable periods of drought stress, making multi-year evaluations necessary to separate true genotype differences from genotype × environment interaction effects. The 2006 rainy season at Jodhpur faced a very late arrival of rains (early August) but a normal ending of the rainy season (late September), with a total rainfall of about 200 mm. Flowering in all trials was early (40 days from emergence) and most trials were subject to post-flowering moisture shortage, resulting in grain yields in the range of 600 to 800 kg ha^{-1}. Despite this, there were significant differences among the hybrids for grain and stover yields, and among lines for the general combining ability.

The ICRISAT-CAZRI B-composite was bred by intercrossing maintainer lines thought to be adapted to the arid zone, and is intended to serve as a source of new, higher yielding seed parents for this zone. Ten lines from this composite along with controls ICMA 95111 and HMS 7A had a significant general combining ability (GCA) effect for earliness which is very encouraging. Three of the B-lines, plus control HMS 7A had significant positive GCA for grain yield. Similarly, three B-lines and two controls (ICMA 93333 and HMS 7A), had significant positive GCA for stover yield. The basic limitation of many of the lines was their non-significant GCA for biomass in this very short season environment, which is a common finding in the case of conventionally bred parental lines that have been selected for high grain yield through high harvest index (HI). In this trial, the relationship of GCA for biomass with grain ($r = 0.78$, $P<.001$) and stover ($r = 0.91$, $P <.001$) yield was very high, underlining the requirement for a positive GCA for biomass under arid zone conditions if new parental lines are to produce hybrids with improved grain and improved stover yields. Two of the 46 lines from this composite and the two controls (ICMA 93333 and HMS 7A), met this requirement.

The Mandor Restorer Composite was bred in a similar fashion as the CAZRI-ICRISAT B-composite, as a source of high-yielding restorers for the arid zone. This composite appears somewhat better adapted to the arid zone, judging by the GCAs of the lines extracted from it. Twelve of the lines had significant GCA for early flowering, as did three of the five controls, and between 5 and 7 of the lines had a significant GCA for grain, stover and total biomass yields. The correlation of GCA for grain yield was high both with GCA for total biomass ($r = 0.84$, $P<.001$) and GCA for HI ($r = 0.82$, $P<.001$). GCA for total biomass was the only determinant of GCA for stover yield ($r = 0.78$, $P<.001$). There was one outstanding line (MRC $S_1$107-1-3-B-B-B) that had significant ($P<.01$) GCAs for early flowering, biomass, harvest index and grain and stover yields. None of the standard inbred controls (which included ICMR 356 and ICMR 01004), apart from the Early Rajasthan Restorer Population, came even close in performance.

The B-line cross trial is specifically designed to identify crosses with a positive GCA for total biomass, from which to select new seed parents to make hybrids with improved biomass productivity in the arid zone. The short rainy season constrained the expression of differences in biomass productivity; only two of the 23 crosses (ICMB 93111 × ICMB 91444 and ICMB 93333 × ICMB 95111) had a significant ($P<0.05$) GCA for total biomass. In both cases the crosses also had a significant ($P<0.05$) GCA for stover yield and positive, if not significant ($P<0.20$) GCA for grain yield. The only cross with a significant positive GCA for grain yield (ICMB 97555 × ICMB 97111) appeared to achieve this by partially escaping the late season drought, as it had a highly significant ($P<0.001$) GCA for early flowering. In such a short season, GCA for early flowering was more closely related ($r = 0.65$, $P<.004$) to GCA for grain yield than was GCA for biomass ($r = 0.54$, $P<.005$) in these materials, which were originally selected for biomass productivity. The data set will be very useful in the ultimate multi-environment analysis, to assess how crosses doing well in more favorable seasons manage a very dry one.

The arid zone restorer populations were bred from diverse arid zone-adapted materials, primarily arid zone landraces, with the intention of providing different source populations from which to breed restorer lines for the arid zone. Because of their landrace backgrounds, these materials are generally good biomass producers; and GCA for grain yield was better related to GCA for harvest index ($r = 0.85$, $P<.001$) than to GCA for biomass ($r = 0.41$, $P = .13$). GCA for grain yield was also related to GCA for early flowering, and two of the three restorers with a significant GCA for grain yield were early flowering - the Early Rajasthan Restorer Population and the control ICMR 01004 (a DM resistant version of H 77/833-2). However both had a negative GCA for stover yield, which approached significance ($P<0.10$) in the case of ICMR 01004. The best overall entry was the Jakharana Restorer Population with positive GCAs for biomass ($P<0.10$), stover ($P<.05$) and grain yields ($P<0.15$), despite its hybrids flowering slightly later than the mean of the trial.

FR Bidinger

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, large panicle and white grain color identified and introgressed (KNR/RB/HDU/RPT/RS, 2009)

Germplasm sources: In search of new germplasm sources for long and compact panicle traits, 25 S_1 progenies (compactness score 7–9 as per the genetic resources characterization data) derived from long panicle germplasm accessions were evaluated during the 2006 postrainy season, of which 18 were selected, producing 76 S_2 progenies for further evaluation during the 2006 rainy season. Of these, 18 progenies were selected, of which 10 flowered in 56–65 days and 2 flowered in 51–55 days (check NCd_2 flowered in 53 days), producing 49 S_3 progenies for further evaluation.

Introgression of panicle and grain traits

Grain size: Large grain size is an important grain yield component and a farmer-preferred trait, especially in Maharashtra state of India. Most of the commercial hybrids and OPVs have 10–12 g of 1000-grain mass, with very few having 15 g of 1000-grain mass. Availability of gemplasm with 19–20 g of 1000-grain mass provides opportunity to develop OPVs and hybrids with 1000-grain mass in excess of 16 g. This germplasm source, however, is highly photosensitive. 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 480 F_5 progenies for gain size and other agronomic traits, 45 were selected (producing 95 F_6 progenies) of which 37 flowered in 56–65 days (47 days for the control ICMB 00444). The remaining 8 were late. There were 24 progenies that had more than 15 g of the 1000-grain mass, with 5 of these having 18–20 g of 1000-grain mass. In another large-seeded seed parent nursery, 196 three-way F_3 progenies had been evaluated. Based on grain size and other agronomic traits, 101 progenies were selected, of which 73 flowered in 51–60 days. There were four progenies that flowered in 46–50 days. Others were late. There were 48 progenies that had more than 15 g of 1000-grain mass, with 6 of these having 18–20 g of 1000-grain mass.

Panicle length: The panicle length of most of the commercial hybrids is 20–25 cm and it rarely exceeds 30 cm. A large number of improved breeding lines developed at ICRISAT have 30–40 cm of panicle length. With panicles as long as 140 cm available in the germplasm, opportunities exist to develop improved breeding lines with 60–80 cm of panicle length. These germplasm accessions, however, are late maturing (70–80 days to flowering) and tall (>250 cm), and have sparse spikelet density in the basal portion of the panicles. Introgression of this long panicle from the germplasm into elite and adaptive backgrounds has met with considerable success. For instance, in restorer parents research, about 645 long spike progenies (F_3-F_8) were evaluated during the postrainy season, of which 164 were selected based on visual assessment for agronomic performance to generate 352 progenies (F_4-F_9) for further advancement. These 352 progenies along with 90 progenies (F_4) coming from rainy season 2005 evaluation were evaluated during the 2006 rainy season. Of these, 105 were selected based on the visual assessment of spike length and agronomic score for further evaluation. About 90 of these flowered in 56−65 days with panicle length ranging between 24 and 83 cm, while 11 progenies flowered in 51−55 days with panicle length ranging from 32 to 48 cm (check NCd_2 flowered in 54 days and had panicle length of 41 cm). There were 13 progenies that had 60−83 cm panicle length.

With the objective of getting good tillering, compact panicles with good exsertion and large seed in long panicle progenies, a crossing program was undertaken during the 2005 summer season. Nine long panicle dwarf progenies (F_4-F_6) were used as female parents and crossed with 17 restorer progenies (F_4-F_9) possessing desirable traits with respect to panicle compactness, good exsertion and tillering. The resulting 124 crosses were evaluated in hybrid observation nursery during the 2005 rainy season, of which 74 were selected based on visual assessment for agronomic traits. Out of 74 F_2s produced, five F_2s derived from F_1s with compact panicles were evaluated in 50-row plots each during the 2005 summer season (all flowering in 55−60 days). Based on visual assessment for agronomic performance, single plant selections were made in four F_2s to generate 260 F_3 progenies for further advancement. Apart from these, another 12 F_2s derived from F_1s with compact panicles were evaluated in 10-row plot each during the 2006 rainy season, of which four flowered in 51−55 days and eight in 56−60 days (check NCd_2 flowered in 53 days). Single plant selections were made in all F_2s to generate 170 F_3 progenies for further advancement.

Grain color: The consumer preference for white grain color in pearl millet stills remains to be ascertained, though the flour of such grains is presumed to be more acceptable for blending with wheat flour. Excellent sources of white seed color are available in the germplasm, but these are highly photosensitive and have small grains. A recent low-key initiative to introgress this 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_4 progenies, which will be further evaluated for selecting those stable for enhanced levels of white grain color.

KN Rai and HD Upadhyaya

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)

Trait-specific seed parent progenies: High grain yield and high levels of DM resistance are common denominators for developing improved breeding lines of pearl millet at ICRISAT. Apart from this, users of this improved germplasm both in the public and the private sector hybrid breeding programs lay considerable emphasis in selecting lines with specific traits, including plant types of the parental lines of some of the commercial hybrids. Thus, improved breeding lines, mostly those at the later stages of the inbreeding, are classified and evaluated in trait-specific nurseries for easy and more focused evaluation, and selection for further utilization. These trait-specific nurseries are continually updated with the new materials generated almost every year.

Early-maturing progenies: We evaluated 430 advanced generation progenies (S_8/F_8/F_{10}), of which 226 were selected based on visual assessment of agronomic traits and yield potential. Of these, 72 progenies flowered in 41−45 days and 145 progenies flowered in 46−55 days (checks 843B flowered in 45 days and 842B in 46 days). About 45 progenies were screened against Durgapura pathotype under high disease pressure in the glasshouse (susceptible checks 842B and 843B had 100% DM incidence), of which 17 progenies had <10% DM incidence. In addition, we also evaluated 1140 F_3 progenies, of which 664 progenies were selected based on earliness and visual assessment of yield potential and agronomic traits. Of these, 95 progenies flowered within 40 days and 475 progenies flowered in 41−50 days (checks 843B flowered in 40 days and 842B in 46 days). More than 2100 F_4 progenies produced from the selected F_3s were evaluated for resistance to Durgapura pathotype under high disease pressure in the glasshouse. Of these, 1170 progenies were highly resistant (<10% DM incidence), and another 300 progenies had 11−20% DM incidence.

Large-seeded progenies: About 140 advanced generation (F_{10}-F_{12}) progenies were evaluated, of which 87 were selected based on visual assessment for large seed and agronomic traits. Of these, 64 progenies flowered in 46–55 days (ICMB 00444 flowered in 47 days). There were two lines that flowered in 40 days. The selected progenies were screened for DM incidence against Durgapura and Jalna pathotypes under high disease pressure (>90%

incidence in susceptible checks) in glasshouse condition. Out of 87 progenies, 52 were highly resistant (0–10% DM incidence) to Durgapura pathotype and 56 were highly resistant to Jalna pathotype.

Long panicle progenies: We evaluated 240 advanced generation progenies ($S_8/F_8/F_{12}$), of which 107 were selected based on visual assessment for panicle length and agronomic performance. Of these, 88 progenies flowered in 56–65 days. There were 11 progenies that flowered in 46–55 days (checks 81B and ICMB 04111 flowered in 55 and 59 days, respectively). Out of 107 selected progenies, 45 were screened against Durgapura and Jalna pathotypes under high disease pressure (susceptible check ICMP 451 had >95% DM incidence), of which 15 were resistant (<20% DM incidence) to Durgapura pathotype, 19 were resistant to Jalna pathotype, and they flowered in 56–65 days. In addition, we evaluated 550 progenies ($S_3/F_5/F_6$), of which 150 progenies were selected. Of these, 128 progenies flowered in 56–65 days (check 81B and ICMB 04111 flowered in 55 and 59 days, respectively). There were 6 progenies that flowered in 51–55 days. Of these selected progenies, 40 had been evaluated against Durgapura pathotype under high disease pressure. Interestingly, all the progenies were highly resistant (<10% DM incidence) and most of them flowered in 51–65 days. We also evaluated 1100 early generation progenies (F_3), of which 320 progenies with 45–60 cm panicle length were advanced based on visual assessment of grain yield potential and morphological characters, producing 950 F_4 progenies.

Thick panicle progenies: We evaluated 386 advanced generation progenies ($S_6/S_7/F_{10}$ onward), of which 160 were selected based on visual assessment for panicle thickness and agronomic performance. Of these, 96 progenies flowered in 51–60 days and 3 flowered in 46–50 days (HHVDBC, the dwarf population, flowered in 55 days).

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 to the extent possible. These so-to-speak secondary traits initially are useful genetic resource. 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 52 advanced generation d_2 dwarf progenies (F_{10} and beyond), of which 33 were selected based on agronomic traits and yield potential, with 24 of these flowering in 46–55 days (ICMB 96555 flowered in 52 days). Similarly, we evaluated 27 advanced generation progenies ($S_5/F_7/F_{10}$), of which 19 were selected based on the panicle compactness and visual assessment of agronomic traits with 14 of these flowering in 46-55 days (check 841B flowered in 51 days). We also evaluated 28 advanced generation progenies (F_9 and beyond), of which 21 were selected for sturdy and erect plant type with 12 of these flowering in 51–60 days (checks 81B flowered in 56 days and ICMB 97111in 48 days).

Specific seed parent-type progenies: We evaluated 142 advanced generation progenies (F_9 and beyond) resembling the broad morphological frames of some of the most popular commercial seed parents (eg., 843A and ICMA 89111), of which 110 progenies were selected with 84 of these flowering in 46–55 days and 6 flowering in 41–45 days (checks 843B flowered in 39 days, ICMB 89111 in 50 days, 81B in 56 days and ICMB 01222 in 55 days).

KN Rai and RP Thakur

Trait-specific restorer progenies: Trait-based seed parent breeding has proved useful in comparative evaluation of breeding lines and their utilization in breeding programs both at ICRISAT and in the NARS and the private sector breeding programs. Thus, a similar approach of trait-based breeding is being followed in restorer development program as well. The trait-based approach is also being followed to develop breeding lines perceived to be adapted to very contrasting agro-ecoregions.

Large-seeded progenies: We evaluated 5 progenies (S_8-S_9) during the 2006 postrainy season. Based on visual assessment for agronomic performance, 4 progenies were selected. This nursery was further upgraded by adding 41 progenies (S_4-S_{10}) from various other restorer parent nurseries. Thus, a total of about 45 progenies (S_5-S_{11}) were evaluated during the 2006 rainy season, of which 34 were selected with 7 of these flowering in 40–50 days and 20 flowering in 51–55 days.

High-tillering progenies: We evaluated 30 progenies (S_9-S_{11}) during the 2006 postrainy season. These were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451 and 834B had 95–98% DM incidence against Durgapura and Jalna pathotypes), of which 16 were highly resistant to Durgapura pathotype, 8 were resistant to Jalna pathotype, and 5 were resistant to both pathotypes (<10% DM incidence). Based on the visual assessment for agronomic performance, and DM incidence, 22 progenies were selected to generate 26 progenies (S_{10}-S_{12}). This nursery was further upgraded by adding 191 progenies (S_3-S_{11}) from various other restorer parent nurseries. Thus, a total of about 215 progenies (S_4-S_{12}) were evaluated during the rainy season, of which 145 were selected with 75 of these flowering in 51–55 days and 20 flowering in 46–50 days (checks ICMR 356 flowered in 50 days and IPC 1268 in 60days).

Thick panicle progenies: We evaluated 12 progenies (S_9-S_{10}) during the 2006 postrainy season. These were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451, and 834B had 95 and 98% DM incidence against Durgapura and Jalna pathotypes respectively) in glasshouse. Of these, 5 were highly resistant to Durgapura pathotype, 4 were resistant to Jalna pathotype and 3 were resistant to both pathotypes (<10% DM incidence). Based on visual assessment for agronomic performance and DM incidence, 7 progenies were selected to generate 9 progenies (S_{10}-S_{11}). This nursery was further upgraded by adding 51 progenies (S_3-S_{10}) from various other restorer parent nurseries. Thus, a total of about 60 progenies (S_4-S_{11}) were evaluated in rainy season 2006, of which 40 were selected with 27 of these flowering in 51–55 days and 4 flowering in 46–50 days (check IPC 1518 flowered in 52 days).

Compact panicle progenies: We evaluated 25 progenies (S_9-S_{11}) during the 2006 postrainy season. These progenies were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451, and 834B had 95–98% DM incidence against Durgapura and Jalna pathotypes) in glasshouse. Of these, 9 were highly resistant to Durgapura pathotype, 4 to Jalna pathotype and 2 were resistant to both pathotypes (<10% DM incidence). Based on visual assessment for agronomic performance and DM incidence, 10 progenies were selected to generate 13 S_{10}-S_{12} progenies. This nursery was upgraded by adding 143 progenies (S_3-S_{11}) from various other restorer parent nurseries. Thus, a total of about 155 progenies (S_4-S_{12}) were evaluated during the 2006 rainy season, of which 100 were selected, with 73 of these flowering in 51–60 days and 14 flowering in 40–50 days (checks ICMP 451 and IPC 1518 flowered in 52 days

Early-maturing progenies: Most of the restorer parent progenies are of medium to mid-late maturity as these are largely derived from improved populations and open-pollinated varieties, which were developed for these maturities. Although these are useful for breeding restorers of dual-purpose hybrids, there has been considerable demand from user programs both in the public and the private sector for early-maturing restorers. Thus, a major initiative has recently been undertaken to breed early-maturing restorer lines.

We evaluated 70 progenies (S_4-S_{10}) during the 2006 postrainy season. These were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451, and 834B had 95-98% DM incidence against Durgapura and Jalna pathotypes) in glasshouse. Of these, 27 were highly resistant to Durgapura pathotype, 19 were resistant to Jalna pathotype, and 8 were resistant to both pathotypes (<10% DM incidence). Based on earliness, visual assessment for agronomic performance, and DM incidence, 44 progenies were selected to generate 61 progenies (S_5-S_{11}). This nursery was further upgraded by adding 186 progenies (S_3-S_{12}) from various other restorer parent nurseries. Thus, a total of about 250 progenies (S_4-S_{13}) were evaluated during the 2006 rainy season, of which 180 were selected, with 63 of these flowering in 46–50 days and 94 flowering in 51–55 days (checks EEBC 407 flowered in 42 days and ICMR 356 in 49 days). Additionally, 39 progenies (all flowering in 46–50 days) were added to further upgrade this nursery.

In another effort, we evaluated 50 progenies (S_3-S_{12}) selected from various trait-specific groups during the 2006 postrainy season to constitute an early-maturing restorer composite. These progenies were also screened against Durgapura and Jalna pathotypes under high disease pressure (ICMP 451 and 834B had >95% DM incidence against Durgapura and Jalna pathotypes). Of these, 13 progenies were highly resistant to Durgapura pathotype and 5 to Jalna pathotype. These progenies were random mated using bulk pollen from all the entries. Based on agronomic scores and DM incidence, crossed seeds from 42 entries were harvested and the hybrids (equivalent to topcross) were evaluated during the 2006 rainy season in unreplicated 4-row plots. Of these, 38 plots were selected, of which 32 flowered in 40–45 days and six in 46–50 days (checks EEBC 407 flowered in 42 days and ICMR 356 in 49 days). Selfing was done in these plots up to 46 days after sowing to select early-maturing plants and produce F_2 seed.

Dual-purpose progenies: We evaluated 140 progenies (S_4-S_{11}) during the 2006 postrainy season. These progenies were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451 and 834B had 95–98% DM incidence against Durgapura and Jalna pathotypes) in glasshouse. Of these, 78 progenies were highly resistant to Durgapura pathotype, 41 were resistant to Jalna pathotype, and 30 were resistant to both pathotypes (<10% DM incidence). Based on visual assessment for agronomic performance and DM incidence, 37 progenies were selected to generate 47 progenies (S_5-S_{12}). This nursery was further upgraded by adding 54 progenies (S_4-S_{11}) from various other restore parent nurseries. Thus, a total of about 100 progenies (S_5-S_{12}) were evaluated during the 2006 rainy season, of which 55 were selected, with 45 of these flowering in 56–65 days and 11 flowering in 46–55 days (checks ICMP 451 flowered in 53 days and HTP 94/54 in 54 days). This nursery was further refined during the 2006 rainy season by constituting three sub-groups (medium-height, medium-tall and tall). Based on visual assessment for height and other agronomic traits, 630 dual-purpose progenies were selected from various other restorer nurseries (including this one). Of these, 350 belonged to medium-height, 200 to medium-tall and 80 to tall groups. In the medium-height group, 255 progenies flowered in 51–60 days and about 60 flowered in 46–50 days. In the medium-tall group, 148 flowered in 51–58 days; and in the tall group, 46 progenies flowered in 51–60 days. The remaining progenies in all the groups flowered in more than 60 days.

Other traits: Besides the above traits of primary importance, there are other traits that add value to the breeding materials, and they also serve as sources of germplasm in elite genetic backgrounds for use in breeding programs. Some of these are: lodging resistance, stay-green and erect growth habit. Thus, about 40 progenies (S_8-S_{10}) were evaluated during the 2006 postrainy season for agronomic traits and more specifically for lodging resistance. These progenies were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451 and 834B had 95–98% DM incidence against Durgapura and Jalna pathotypes) in glasshouse. Of these, 13 were highly resistant to Durgapura pathotype and 3 to both pathotypes (<10% DM incidence). Based on visual assessment for agronomic performance and DM incidence, 21 progenies were selected to generate 24 progenies (S_9-S_{11}). This nursery was further upgraded by adding 18 progenies (S_3-S_{11}) from various other restorer parent nurseries. Thus, a total of about 42 progenies (S_4-S_{12}) were evaluated in 2006 rainy season, of which 23 were selected, with 16 of these flowering in 51–60 days and 4 flowering in 46–50 days (checks ICMR 356 flowered in 50 days and ICMP 451 in 52 days). Similarly, 100 progenies (S_5-S_{12}) were tested in the postrainy season drought nursery for stay-green trait, of which 44 progenies were selected based on visual assessment for stay-green and agronomic performance, with 33 of these flowering in 56–60 days and 3 flowering in 46–55 days (check ICMR 356 and ICMP 451 flowered in 56 days). These were also evaluated in the breeding nursery, of which 70 progenies were selected and further evaluated during the 2006 rainy season. Of these, 46 were selected, with 32 flowering in 51–60 days and 2 progenies flowering in 46–50 days (checks ICMR 356 flowered in 50 days and ICMP 451 in 51 days). We also evaluated 82 advanced generation progenies (S_5-S_{11}) for erect growth habit, of which 58 were selected, with 39 of these flowering in 51–60 days and 12 progenies flowering in 46–50 days (check IPC 804 flowered in 50 days).

Specific restorer-type progenies: Parental lines of commercial hybrids or lines identified as good general combiner and with farmer-preferred traits occasionally become reference lines with users of ICRISAT-bred lines requesting seed of breeding lines depicting traits or trait combinations of the reference lines. ICMR 356 (restorer of a commercial hybrid) with short height, high tillering; and IPC 804 with short height, long panicles, and erect growth habit are two such reference lines that were used for grouping of restorer parent progenies. We evaluated about 50 ICMR 356 type progenies (S_3-S_{11}) during the 2006 postrainy season These progenies were also screened against both Durgapura and Jalna pathotypes under high disease pressure (susceptible checks ICMP 451 and 834B had 95–98% DM incidence against Durgapura and Jalna pathotypes). Of these, 15 were highly resistant to Durgapura pathotype, 10 to Jalna pathotype, and 4 to both pathotypes. Based on visual assessment for agronomic performance and DM incidence, 24 progenies were selected to generate 35 progenies (S_4-S_{12}). This nursery was further upgraded by adding 66 progenies (S_3-S_{11}) from various other restorer parent nurseries. Thus, a total of about 100 progenies (S_4-S_{12}) were evaluated in rainy season 2006, of which 56 were selected, with 23 of these flowering in 46–50 days and 28 flowering in 51–55 days (check ICMR 356 flowered in 49 days). Similarly, we evaluated 85 IPC 804 type progenies (S_4-S_{11}) during the postrainy season. These progenies were also screened against both Durgapura and Jalna pathotypes under high disease pressure. Of these, 37 were highly resistant to Durgapura pathotype, 13 to Jalna pathotype, and 9 to both pathotypes (<10% DM incidence). Based on visual assessment for agronomic performance and DM incidence, 40 progenies were selected to generate 50 progenies (S_5-S_{12}). This nursery was further upgraded by adding 48 progenies (S_3-S_{11}) from various other restorer parent nurseries. Thus, a total of about 100 progenies (S_4-S_{12}) were evaluated in rainy season 2006, of which 62 were selected, with 44 of these flowering in 46-55 days (check IPC 804 flowered in 50 days). Another 190 progenies, of which 142 flowered in 46−55 days, were identified during the 2006 rainy season to further upgrade this group.

Restorer parent progenies with specific agro-ecological adaptation: The two most contrasting agro-ecoregions in India that require different plant types and seed traits are Rajasthan (specifically western Rajasthan) and Maharashtra. Thus, for Rajastahn adaptation (largely high-tillering type with small to medium seed size), we evaluated 87 (S_7-S_{12}) progenies, of which 60 were selected, with 47 of these flowering in 46−55 days and one progeny flowering in 40 days (checks H 77/833-2 flowered in 44 days and ICMR 356 in 47 days). About 300 additional progenies were identified as Rajasthan-adapted type and added in the group for further evaluation, of which 150 flowered in 51−55 days and 95 in 46−50 days. For Maharashtra adaptation (mostly *iniari* type with dark gray color and medium to large grains), we evaluated 26 advanced generation progenies (S_7-S_{12}), of which 14 were selected, with 13 of these flowering in 46−55 days (check ICTP 8203 flowered in 47 days). During the rainy season, two sub-groups within the *iniari* type (early and medium height) comprising of 320 progenies were constituted based on days to 50% flowering and visual assessment for plant height and agronomic performance. Out of 320 progenies, 22 belonged to early group and 300 to medium-height group. Among early-maturing progenies, all flowered in 40−50 days, while of those in the medium-height group, 50 flowered in 40−50 days and 165 flowered in 51−55 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. Though these materials are carried forward in this structure, some of the most promising ones, mostly at F_5 and beyond, are also included in the trait-specific groups until all those surviving selections up to the final stage are grouped into trait-specific classes or rejected in the final evaluation.

Early-generation progenies (S_1-S_3): This consisted of *iniari* type progenies (S_1/S_2) from ICTP 8202 and LaGrap, and dual-purpose progenies from seven populations. We evaluated 107 progenies from ICTP 8202 in the postrainy season drought nursery, of which 56 were selected based on agronomic performance, with 33 of these flowering in 51−55 days and 16 flowering in 40−50 days (check ICMR 356 flowered in 56 days). About 120 S_2s were generated for further evaluation. In LaGrap, we evaluated 106 progenies (S_1/S_2) during the rainy season, of which 67 were selected with 11 of these flowering in 40−45 days and 35 flowering in 46−50 days (check ICMP 451 flowered in 52 days). About 95 (S_1) progenies were screened against Durgapura pathotype in glasshouse under high disease pressure (susceptible check ICMP 451 had >95% DM incidence), of which 65% progenies had <10% DM incidence. In the dual-purpose group, we evaluated 852 S_1/S_3 progenies derived from seven populations (including OPVs), of which 238 were selected, with 27 of these flowering in 46−50 days and 181 flowering in 51−60 days (checks ICMP 451 flowered in 52 days and HTP 94/54 flowered in 53 days).

Advanced generation progenies (S_5-S_{11}): This also consisted of both *iniari* type progenies derived from GB 8735 and non-*iniari* type progenies from four OPVs. Of the 67 progenies derived from GB 8735 and evaluated in 2006 rainy season, 41 were selected with 18 of these flowering in 51−60 days and 9 flowering in 46−50 days (checks ICMR 356 flowered in 50 days and IPC 1518 in 53 days). In the dual-purpose group, we evaluated 770 S_5/S_{11} progenies, of which 248 progenies were selected, with 52 of these flowering in 46−50 days and 174 flowering in 51−60 days (checks ICMP 451 flowered in 51 days and HTP 94/54 in 53 days). The DM resistance level of the material in this nursery seems quite high for Durgapura pathotype as the evaluation of a subset of 196 progenies belonging to JBV 2 and JBV 3 during summer season against this pathotype under high disease pressure (check ICMP 451 had >95% DM incidence) showed that 69% of it were highly resistant (<10% DM incidence).

A_5 restorer development: About 120 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 63 were selected based on the visual assessment of agronomic traits. In addition, 65 F_2 populations were generated from fertile F_1 plants that had been produced by crossing elite inbred lines on fertile plants of eight initial F_2 populations during the 2005 summer season.

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) were screened against Durgapura pathotype under high disease pressure during the postrainy season. These had 13 and 51% DM incidence, respectively. About 600−700 DM-free F_2 plants from these populations were transplanted, selecting 104 plants (66 and 38 plants, respectively) that were evaluated during the rainy season. Of these, 51 progenies were selected (39 and 12 progenies, respectively), based on the visual assessment for agronomic performance. Of these, 45 progenies flowered in 51–60 days and 4 in 46–50 days (checks ICMR 356 flowered in 51 days and ICMP 451 in 52 days).

KN Rai and RP Thakur

Genetics of panicle and grain size: Panicle length and girth (determinants of the seed number per panicle) and grain mass are the two of the important yield components of grain yield. Numerous studies have investigated the genetics of these three traits, but never before with as large parental contrasts as those now available in the ICRISAT-bred lines. Thus, a renewed effort is underway to investigate the genetics of these three traits using lines that have 70 cm of panicle length, >45 mm of panicle diameter and >16 g of 1000-grain mass. During the 2005 postrainy season, four parents of almost similar maturity but with large contrasts for these traits were crossed to produce 6 F_1s (2 for each trait). During the rainy season, all the parental lines along with their F_1s, F_2s and backcrosses (seed produced in the glasshouse) were evaluated in a randomized complete block design with three replications. Observations on quantitative traits like plant height, number of productive tillers, panicle length and diameter were recorded on all the plants in F_2s and backcross progenies, while these observations were recorded on 30 randomly selected plants in parental lines and F_1s. The data on 1000-grain mass is yet to be recorded. Additionally, seeds of triple testcross (TTC) progenies have been produced during rainy season by crossing more than 60 F_2 plants as male parent onto respective parents and their F_1s, which will be evaluated during the 2007 postrainy season to provide the additional information on the inheritance pattern of the targeted traits.

KN Rai

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)

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/RV, 2008)

Two-season characterization of 108 A/B pairs and 88 restorer lines for 26 characters from replicated trials was completed. The data were computerized in a catalogue format and field photographs have been taken for the A/B lines. The data computerization for the R-lines and their field photographs are yet to be completed.

KN Rai, Ranjana Bhattacharjee and Rajeev Varshney

Milestone 5A.3.1.2: Selected hybrid parents and advanced breeding lines characterized for morphological and molecular diversity, and yield heterosis (KNR/RB/RV, 2008)

This research is to start in 2007.

KN Rai, Ranjana Bhattacharjee and Rajeev Varshney

Milestone 5A.3.1.3: Two medium-maturity heterotic gene pools based on molecular marker diversity constituted (KNR/RB/SC/RV, 2012)

This project is to start in 2007.

KN Rai, Ranjana Bhattacharjee, S Chandra and Rajeev Varshney

Output target 5A.4: QTLs 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)

To be reported in 2008

Milestone 5A.4.1.2: Genetically diverse parents of mapping populations identified and crossed to generate F_6 RILs (CTH/KNR/RPT/RS, 2007)

To be reported in 2007

Activity 5A.4.2: Map-directed conventional backcrossing and marker-assisted backcrossing of DM resistance QTLs into parental lines of hybrids

Milestone 5A.4.2.1: Ten major QTL imparting resistance against specific DM pathtypes identified (CTH/RPT/RS, 2007)

To be reported in 2007

Milestone 5A.4.2.2: Near-isogenic lines containing different DM resistance genes (QTL) developed (RPT/RS/CTH, 2010)

Near-isogenic lines of pearl millet possessing resistance genes effective against different pathotypes of DM can be used as a set of host differentials for monitoring virulence shift in the pathogen isolates. A number of DM resistance QTLs effective against different pathotypes have been mapped from different resistance sources and introgression of these QTLs into elite B-lines is in progress. During 2006, we evaluated in greenhouse about 560 backcross progenies in different generations ($BC_{3F1.F2}$ to BC_{6F1}) against two pathotypes Sg 298 (New Delhi) and Sg 409 (Patancheru). These progenies carried the DM resistance QTLs from IP 18293, P 1449-2 and 863B-P_2 that were introgressed into three elite hybrid parents 843B, 81B and 841B. About 15 to 30% of the progenies in the phenotypic background of the above three B-lines were found resistant (≤10% incidence) compared to 84–99% incidence on the susceptible checks. Several other DM resistance QTLs have been introgressed into 843B and these are at different stages of development. Detailed data analysis is in progress.

RP Thakur and CT Hash

Milestone 5A.4.2.3: QTL with known effects against diverse pathotypes pyramided in 843B and other parental lines and their resistance levels determined (CTH/RPT/RS, 2010)

QTL with known effects against diverse pathotypes pyramided in 843B and other parental lines and their resistance levels determined (CTH/RPT/RS, 2010) Single QTL introgression continued (see Milestone 5A.4.2.4 below) to maximize recovery of hybrid parental line recurrent parent genetic backgrounds, which must be completed before initiation of a crossing and marker-assisted selection program to pyramid QTLs from different sources in common recurrent parental line backgrounds in a species such as pearl millet where marker distribution and density is less than optimal.

Milestone 5A.4.2.4: Several different single-QTL introgression homozygotes available in genetic backgrounds of two elite seed parents (CTH/RPT/RS, 2007)

A major QTL for downy mildew resistance, from linkage group 4 of 863B-P2, was advanced from BC6F1 to BC6F2/BC7F1 pairs and from BC5F2 to BC5F3 progenies in the genetic background of ICMB 841. Backcrossing advanced by two generations to BC4F2/BC5F1 pairs for several downy mildew resistance QTLs from donor P1449-2-P1 in the genetic background of 843B. The resistant allele for one of these QTLs is linked to the tall height allele at the d2 dwarfing gene locus on pearl millet linkage group 4. Similarly, backcrossing advanced by one generation to BC3F2/BC4F1 pairs for several downy mildew resistance QTLs from donor IP 18293 in the genetic background of elite seed parent maintainer lines 81B and 843B.

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)

Crossing was initiated for marker-assisted backcrossing programs to introgress downy mildew resistance QTLs from several donor parents (including P1449-2, P310-17, ICMB 90111-P6, PRLT 2/89-33 and 863B-P2) into the genetic backgrounds of several elite hybrid parental lines chosen by national program partners in India (including restorer lines J 2340, H 77/29-2 and ICMR 01004 as well as seed parent maintainer lines HMS 7B, ICMB 93333, and ICMB 95444).

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 survey are characterized for pathogenicity and virulence. Highly virulent isolates thus identified are used for screening breeding lines for developing downy mildew resistant hybrid parental lines.

Pathogenic variation: Eleven isolates collected from five districts (Jamnagar, Anand, Kheda, Banaskantha and Gandhinagar) of Gujarat during the on-farm survey of 1998–2005 were established on potted pearl millet seedlings of 7042S in a glasshouse. The pathogenicity and virulence diversity of these isolates were determined by inoculating the pot-grown seedlings of a set of eight host differential lines (P 7-4, P 310-17, 700651, 7042R, IP 18292, IP 18293, 852B and ICMP 451) and a susceptible check 7042S. The experiment was conducted with 11 isolates, 9 host differentials and 3 replications with 30–35 seedlings/replication in a completely randomized design (CRD). The latent period$_{50\%}$ was recorded from 4th day onwards after inoculation and disease incidence 2 weeks after inoculation. Based on latent period$_{50\%}$ and disease incidence, virulence index (disease incidence × latent period^{-1}) was calculated to measure the quantitative virulence of the isolates. The results indicated that of the 11 isolates Sg 441 and Sg 445 (from Banaskantha) were the more virulent with mean incidence of 78–84% across 9 host differentials, and Sg 348 (from Anand) was the least virulent (26% incidence). The dendrogram based on the virulence index using the Euclidean square distances (the average linkage cluster analysis) classified these isolates (at 90% similarity coefficient) into four groups- Sg 200, Sg 348 and Sg 442 in Gr 1 (less virulent); Sg 432, Sg 438, Sg 439, and Sg 440 in Gr 2 (moderately virulent); Sg 435 and Sg 437 in Gr 3 (virulent) and Sg 441 and Sg 445 in Gr 4 (highly virulent). The isolate Sg 445 is currently being used to screen breeding lines targeted for Gujarat.

RP Thakur

Effectiveness of pathotypes mixture for screening breeding lines: Development of improved breeding lines as potential parental lines (A-, B- and R-lines) of hybrids with high level of DM resistance has been the major research focus at ICRISAT. These breeding lines are routinely screened against individual pathotypes in succession to identify those with resistance to single or multiple pathotypes. Many times, a question is asked what if the pearl millet lines could be evaluated against a mixture of pathotypes instead against individual pathotypes in order to reduce time and save resources. To address this issue, an experiment was conducted to test the relative efficacy mixture of two pathotypes - Sg 150 from Jalna, and Sg 212 from Durgapura along with the individual pathotypes for screening pearl millet lines. Twelve pearl millet lines (P 7-4, P 310-17, 700651, 7042R, 852B, 834B, 843B, IP 18292, IP 18293, 863B, ICMB 03999 and S 2003-188) known for their differential reactions to these pathotypes and two susceptible checks (7042S and ICMP 451) were used. Experiment was conducted in CRD with three treatments of pathogen and 14 genotypes in 6 replications (one pot/replication with 35–40 seedlings). The experiment was repeated to confirm the results. The results indicated that the pearl millet lines that were highly susceptible to either or both pathotypes were also highly susceptible to pathotype mixture, and the lines that were not highly susceptible to either of the pathotype had average susceptibility. Thus, the use of pathotype mixture would serve the purpose of discarding the highly susceptible lines. However, screening against specific pathotypes may provide more reliable data on resistance levels of the genotypes.

RP Thakur

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)

Virulence monitoring in pearl millet downy mildew: The downy mildew pathogen, *Sclerospora graminicola*, evolves fast in response to selection pressure imposed by host resistance gene(s). Occurrence of new virulence and virulence shift is monitored through on-farm surveys and multilocation virulence nursery.

On-farm downy mildew survey: Under the ICAR-ICRISAT partnership project, roving surveys were conducted in Gujarat, Maharashtra and Rajasthan in collaboration with AICPMIP pathologists of the respective states during the summer and rainy seasons. In Gujarat, during summer, a total of 70 pearl millet fields were surveyed in six talukas of two districts (Mehasana and Banaskantha) where summer pearl millet is important. Of the 70 fields surveyed, 41 (58%) had DM incidence ranging from 1 to 93%. Of the three public sector hybrids observed, HHB 67 had 11% incidence and the other two hybrids, GHB 557 and GHB 558 were DM-free. Of the 23 private sector hybrids, 11 (Bioseed, HY 555, M-50, Nandi 5, Nandi 52, PAC 982, Pioneer 86M34, Pioneer 86M52, Proagro 9444, Raasi 2246 and Ritu) were disease-free, six (Chandini 511, Nandi 35, Nirmal 1651, NK 1616, Paras Sarpanch and Proagro 9555) were resistant (1−10% incidence) and the remaining six (Ajay VBBH 334, Nandi 32, Paras Ganesh, Pioneer 7777, Rani, and Seedtek) were susceptible (30−61% incidence).

In Maharashtra, we surveyed a total of 99 pearl millet fields in 18 talukas of 7 districts, (Ahmadnagar, Aurangabad, Beed, Dhule, Jalgaon, Jalna and Nashik) during the rainy season. There were 15 private sector hybrids (Amar Ratna 6, Anuja 6, Hy. 555, MBH 163, MDBH 318, MLBH 308, MLBH 367, MLBH 504, MRB 204, MRB 212, MRB 2210, Nirmal 1651, Pioneer 86M34, Proagro 9330 and Tulja) and all were disease free.

In Rajasthan, a total of 123 pearl millet fields in 20 talukas of 7 districts (Alwar, Dousa, Jaipur, Karouli, Sawai Madhopur, Sikar and Tonk) were surveyed during the rainy season. Of the 123 fields surveyed 93 (76%) showed DM incidence ranging from of 1−96%. Of the 24 private sector hybrids observed, 3 (JKBH 598, Kanchan and MRB 2210) were disease free, 4 (JKBH 26, Nirmal 1651, Proagro 9444 and Pioneer 86M52) were resistant (1−5% incidence) and the remaining 17 were susceptible (Akash, Ankur 2226, Anmol, Arjun, Aswani, Bioseed 8510, Sri Hari Krishna 1044, Kaveri 456, MLBH 75, MLBH 308, PAC 982, PG 5850, Pioneer 7688, Pioneer 86M32, Pioneer 86M34, Rani and RBH 36) were susceptible (37−96% incidence). One public sector hybrid, ICMH 356 found in just 2 fields was also disease free. Most of the seed companies supplied the metalaxyl-treated seeds to the farmers.

We believe that the absence of DM in several hybrids and high levels of resistance in some other hybrids may require confirmation of their genetic resistance as most of the seed were treated with metalaxyl. In addition, lack of disease in Maharashtra could be due to the initial dry spell of about 20 days after planting and the practice of different cropping sequences, such as soybean-cotton-millet; wheat-cotton-millet, sorghum-cotton-millet; maize-cotton-millet; cotton-castor-millet and onion-cotton-millet that affect initial soil inoculum level. This needs further investigation.

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)

Germplasm sources: 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. Ten germplasm accessions visually selected for high forage yield during the 2005 rainy season were planted for producing S_1 progenies. In addition, three of the most promising accessions were random mated to develop an open-pollinated forage variety ICMV 06111. 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, is now routinely used as a control in forage trials. In a preliminary yield trial conducted during the 2006 rainy season, ICMV 06111 gave 9.1 t ha^{-1} of dry forage yield at 80-d harvest, which was 90% of the forage yield of ICMA 00999 × IP 17315 and comparable to that of Proagro 1 (8.9 t ha^{-1}). ICMV 06111 flowered in 87 days compared to 69 days for ICMA 00999 × IP 17315 and 54 days for Proagro 1.

KN Rai and HD Upadhyaya

Milestone 5A.6.1.2: Improved populations and experimental hybrids with high forage yield potential developed (KNR/RB/ HDU/MB, 2009)

Open-pollinated varieties hybrids with high forage yield: Nine OPVs developed for forage purposes have now been evaluated for two years (rainy season of 2005 and 2006) at Patancheru. Based on the mean performance across the two years, ICMV 05555 was found to be the highest-yielding, giving 14.8 t ha^{-1} of dry forage yield at 80-d harvest, which was 14% more than that of the control (ICMA 00999 × IP 17315). Another variety ICMV 05777 gave 13.1 t ha^{-1} of the dry forage yield, which was comparable to that of the control (13.0 t ha^{-1}). ICMV 05555 flowered in 70 days and ICMV 05777 in 74 days compared to 69 days for the control. There were five additional varieties that had 10.3–11.9 t ha^{-1} of the dry forage yield. Two of these flowered in 60 and 65 days, one in 78 days, while the other two flowered in 94 days. The yield potential of the latter two is likely to be higher if harvested at 90-95d harvest.

Twenty-seven topcross hybrids produced by crossing three forage type male-sterile lines (ICMA 89111, ICMA 00999 and ICMA 03222) with each of the nine forage populations were evaluated during the 2005 and 2006 rainy seasons for forage yield at 50 and 80-day harvest. Based on the mean performance over the two seasons, seven hybrids (3 on ICMA 89111 and 4 on ICMA 00999) produced 12.5-13.8 t ha^{-1} of dry forage yield (11.8 t ha^{-1} for control hybrid, ICMA 00999 × IP 17315) at the 80-d harvest. The highest yield was obtained for hybrid ICMA 00999 × ICMV 05222 (13.8 t ha^{-1}). All the selected hybrids flowered in 65–75 days (72 days for the check hybrid).

KN Rai, HD Upadhyaya and Michael Blümmel

Milestone 5A.6.1.3: Diverse seed parents with high forage yield potential developed and characterized (KNR/RB/MB, 2012)

Hybrid parents progenies: We evaluated 24 advanced generation progenies (F_6/F_9), of which 18 were selected based on the visual assessment of forage yield. Of these, 17 flowered in 51–60 days (checks ICMB 00999 flowered in 47 days and ICMB 98777 in 58 days). Sixteen potential forage type seed-parental lines with 50–60 days of flowering were intercrossed during the postrainy season. The resulting 16 F_1's were evaluated during the 2006 rainy season for biomass, of which 10 were selected based on the visual assessment of forage yield, with their flowering ranging between 50 and 55 days. We also evaluated 155 S_2/S_6 population progenies (earlier selected for high biomass yield) during the 2006 rainy season, of which 60 were visually selected for high biomass yield, producing 120 progenies. Most of the progenies flowered in 50–60 days (check ICMP 451 flowered in 50 days).

KN Rai and Michael Blümmel

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)

The field trial data from two years and 2–3 locations have been analyzed, showing that the hybrids based on the A_4 cytoplasm give about 5% less grain yield than those based on the A_1 cytoplasm, although there is large cytoplasm × genotype interaction. These results will be written up for formal publication in 2007/2008.

KN Rai

Milestone 5A.7.1.2: Genetical studies of diverse CMS systems completed (KNR/RB, 2009)

This research was a part of a PhD thesis that was completed in 2005. Drafts of the genetics of two CMS systems have been prepared. The publication of this work will start in 2007 and will be completed by 2009.

KN Rai and Ranjana Bhattacharjee

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)

In response to seed requests, 1200 seed samples were supplied to public and private organizations (263 public and 937 private) within India, and about 730 samples of breeding materials supplied to about 10 countries abroad (Africa, USA and UAE). We produced 400 kg breeder seed of ICTP 8203 and 228 kg was supplied from the carry-over stock. Also, we supplied 320 kg breeder seed of seven hybrid parental lines. In addition, about 300 kg breeder seed of two seed parental lines (ICMA/B 89111 and ICMA/B 93333) was multiplied.

KN Rai

Milestone 5A.8.1.2: ICRISAT's research partnerships with NARS, networks and regional fora strengthened ((KNR/CLLG/Pearl Millet Team, annual)

Under the ICAR-ICRISAT partnership project, 8 trials (6 hybrid trials, and one each of biofortification and salinity trials) and 11 nurseries (7 maintainer and 4 restorer lines) were constituted and sent to the AICPMIP coordinator for coordinating the evaluation at 14 locations. NARS and the private sector scientists were involved in planning for an international course on Pearl Millet Improvement and Seed Production and also serving as resource persons. NARS scientists were increasingly involved in project development, joint publications, and facilitation of a research grant from ICAR for DM resistance marker selection work.

During a brief visit to two research centers in Mexico, presentations were made on adaptation and yield potential of pearl millet for grain and fodder production to assess the prospects of pearl millet and develop possible research collaboration for introducing this crop for crop diversification in that country. Similar presentations were made and pearl millet and sorghum trials evaluated during a 2-week visit to several research stations and universities in Central Asia (Uzbekistan, Turkmenistan and Kazakhstan) to assess the prospects of pearl millet in this region. There is keen interest among NARS to introduce pearl millet for crop diversification and farmers livelihood improvement in Central Asia and Mexico. Also, linkages were developed for testing the prospects of pearl millet in Morocco and China.

ICRISAT-Private Sector partnership was further strengthened with 20 new seed companies joining the Pearl Millet Hybrid Parents Consortium in 2006, taking it to a total of 34 consortium members. Maharashtra State Seed Corporation, the first public-sector seed producing agency coordinated a 21-entry trial of consortium hybrids from 10 seed companies at 9 locations, including Patancheru. Analysis of Patancheru data showed that none of the hybrids produced higher grain yield over the high-yielding check 7688 (4330 kg ha^{-1}). However, for dry fodder yield, the hybrids of GK 1059 and KH 325 were 35 and 9% superior over the check 7688 (4480 kg ha^{-1}), and the flowering of all the entries ranged between 46 and 52 days, while 7688 flowered in 48 days and HHB 67-2 in 38 days

KN Rai, CLL Gowda and Pearl Millet Team

Milestone 5A.8.1.3: International Pearl Millet Training Course (2009) and Field Day (2006, 2008, 2010, 2012) conducted (KNR/CLL/Pearl Millet Team)

Pearl millet scientists field day: Pearl Millet Scientists Field Day held on 14–15 September 2006 at ICRISAT, Patancheru had 60 scientists from 12 public and 32 private organizations. The participants selected breeding lines and potential parents (A-, B- and R-lines) of hybrids for utilization in their programs. All the private sector requests have been obtained and consolidated which shows that 1382 breeding lines/parental lines of potential hybrids were selected by these companies with a total of 5420 seed samples as some of the lines were selected by more than one seed company (more than 7 companies requested a few lines).

International training course on pearl millet improvement and seed production: An international training course on pearl millet improvement and seed production was held on 2–15 May 2006 at ICRISAT, Patancheru. The course was initially co-sponsored by the FAO. Subsequently, INTSORMIL, USA; ICBA, Dubai, The Sehgal Foundation, India; and Syngenta Foundation, Switzerland also co-sponsored this course. Besides ICRISAT scientists (11), resource scientists from national (3) and private sector (8) in India, along with one scientist from USA, were included as resource persons for the training. About 40 trainees (including 5 women) from 15 countries participated in the training, of which 19 participants were from private seed companies and 9 from public sector institutions within India; 7 from Africa; 4 from Middle-East; and one each from USA, Uzbekistan, Pakistan and Myanmar. The training course consisted of several lectures, practical classes, visits to field and private seed companies and group discussions. The success of the training course was evaluated by providing questionnaires to the participants. In a group exercise, they also identified 11 major constraints in pearl millet production. Six participants also took the opportunity to select more than 500 breeding lines (including hybrid parental lines, improved populations and germplasm accessions) and also requested for ICRISAT's assistance in supplying breeding materials, organizing drought and salinity nurseries, and guiding their breeding programs. The general opinion was to conduct this training course once in 3 years. Participants also suggested for conducting similar training courses in biotechnology and data analyses.

KN Rai, CLL Gowda and Pearl Millet Team

Milestone 5A.8.1.4: Technical information and public awareness documents developed and disseminated (KNR/CLLG/Pearl Millet Team, annual)

Two flyers were prepared in collaboration with the International Center for Biosaline Agriculture (ICBA). One of this deals with salinity tolerance of sorghum and pearl millet and the other one deals with the prospects of these crops in Central Asia. A booklet describing pearl millet cultivars for dry environments was brought out as a joint publication of ICRISAT and ICAR. Pearl millet as a highly nutritious cereal for grain iron and zinc was publicized through a poster at the International Plant Breeding Symposium in Mexico.

Milestone 5A.8.1.5: Commercialization of pearl millet grains strengthened through researcher-farmer-industry alliances (KNR/CLLG/Pearl Millet Team, annual)

Plans were developed under the CFC-funded project for on-farm trials of pearl millet in Andhra Pradesh (AP) and Maharashtra village clusters to enhance pearl millet productivity through cultivar replacement and micronutrient applications. Based on the results during 2005, the popular pearl millet variety ICTP 8203 in the AP village clusters was almost completely replaced with a pearl millet hybrid (MLBH 308) that showed substantial yield advantage. The data on the grain and fodder yield of new cultivars over those grown by the farmers (both with and without micronutrient applications) were collected to examine the income generation values of the recommended practices.

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/KML, 2006-09)

During 2006 rainy season, 227 short-duration and 234 medium-duration new hybrids were evaluated for fertility restoration. Of these, 298 hybrids (64.6%) had full pollen fertility and 33 (7.2%) were male-sterile, while the remaining segregated for male-fertility and sterility in various proportions. All the male-sterile F_1s were backcrossed to their respective male-parents to produce BC_1F_1 seed for the diversification of A-lines. Among the fertile hybrids, the promising combinations will be selected to produce hybrid seed again for confirming their fertility restoration and agronomic performance.

KB Saxena and K Madhavi Latha

Milestone 5A.1.1.2: At least five high yielding hybrids each in early and medium maturity duration identified for multi-location testing (KBS/KML, 2007)

A total of 405 new experimental hybrids were evaluated for their agronomic performance in 20 station trials at Patancheru. Due to frequent rains during early growth stages, the short-duration experiments were damaged by intermittent water-logging and phytophthora blight and eight trials were abandoned. In the remaining four trials, the yield levels were low when compared with the previous season. Among these hybrids, ICPH 3538 (2014 kg ha^{-1}) was found to be the best with 92% superiority over the control ICPL 88034 (1027 kg ha^{-1}). The other promising hybrid in this group was ICPH 3548 (1832 kg ha^{-1}, 78% superiority). The data from medium-duration hybrid trials are awaited.

KB Saxena and K Madhavi Latha

Milestone 5A.1.1.3: At least five pigeonpea hybrids identified for on-farm testing (KBS/KML, 2008)

Based on the performance of hybrids in multilocation trials conducted in 2005 rainy season and the availability of seed, one short-duration hybrid (ICPH 2438) and one medium-duration hybrid (ICPH 2671) were evaluated at 20–25 farmers' fields in Maharashtra, Karnataka and Andhra Pradesh by cooperating NARS partners and seed companies. The data are awaited.

In order to identify new hybrids for on-farm testing in 2007 rainy season, 24 short-duration hybrids are being evaluated at 10 locations. Similarly, in the medium-duration group 32 hybrids are being evaluated at 15 locations. The parental seeds of these hybrids are being multiplied either in isolation or under insect-proof cages.

KB Saxena and K Madhavi Latha

Milestones 5A.1.1.4: Elite pigeonpea hybrids evaluated for their resistance to major insects and diseases (2009)

Four hundred and eighty-one hybrids and their parents were evaluated for wilt and SM resistance under artificial epiphytotic conditions following standard field evaluation techniques. Wilt-susceptible ICP 2376 and SM-susceptible 8863 were sown after every 10 test entries as infector-cum-indicator rows. Of these, 11 hybrids, ICPHs 2324, 2373, 3183 (ICPL 20106), 3224 (ICPL 87051), 3363, 3450, 3476, 3477, ICPR 2337 (ICPL 20106), ICPLs 87119, ICPL 20110, were found asymptomatic, while 21 were found resistant with <10% disease incidence of both wilt and SM.

Suresh Pande and KB Saxena

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_4 male-sterile and 15 fertility restorer lines with resistance to wilt and sterility mosaic disease developed (2007)

Three hundred and eleven A_4 male-sterile lines and their restorers were evaluated under artificial epiphytotic conditions following standard field evaluation techniques for combined resistance to wilt and SM. Four lines, ICPB 2092 (ICPL 96058), ICPR 2926 (ICPL 20129), ICPR 2352 (ICPL 94068) and ICPL 99044 were found asymptomatic to both wilt and SM diseases, while 29 lines had combined resistance (<10% wilt and SM diseases). Two lines, ICPA 2048 and ICPA 2087 were asymptomatic for wilt and 63 lines for SM.

Suresh Pande and KB Saxena

Milestone 5A.2.1.2: At least six promising maintainers of A_4 cytoplasm improved for agronomic traits (seed and pod size and disease resistance) through backcrossing (KBS/KML, 2009)

In any dynamic hybrid breeding program the genetic enhancement of female parents for desired agronomic traits is essential to develop promising hybrid combinations. To increase the pod size of promising A-lines, ICPA 2039 and ICPA 2089 were crossed with a white seeded variety 'Kanchan'. Similarly, crosses are being initiated to incorporate sterility mosaic and wilt resistance in ICPA 2044 and ICPA 2045.

KB Saxena and K Madhavi Latha

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/KML/HCS/SP, 2008)

During the 2006 rainy season, 26 maintainer lines and 22 restorer lines were evaluated in separate replicated trials at Patancheru. The data are being compiled on a number of qualitative and quantitative traits. We propose to repeat this trial in 2007 rainy season also. This information will be shared with the germplasm unit and also will be used for registration and selection of hybrid parents in the future.

KB Saxena, K Madhavi Latha, HC Sharma and S Pande

Relative susceptibility of maintainer and restorer lines to *Helicoverpa armiger:* Fifteen restorers and 13 maintainer lines along with resistant (ICPL 187-1, 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 pod damage and overall resistance scores at maturity. The overall resistance scores ranged from 4.5 to 9.0. The maintainer lines ICPB 2032, ICPB 2049, ICPB 2050, and ICPB 2051 showed a damage rating of 5.5 to 6.0 compared to 8.2 in ICPL 87 and 4.5 in ICPL 332. Percentage pod damage ranged from 75.7 to 86.4%. Most of the lines (except ICPB 2032, ICPB 2043, ICPB 2046, ICPB 2046, and ICPB 2048) were highly susceptible to wilt (over 80% mortality).

Among the restorer lines, the genotypes ICPR 2913, ICPR 2920, ICPR 2922 showed a damage rating of 4.7 to 6.0 compared to 4.5 in ICPL 332 and 8.2 in ICPL 87. Pod damage was 56.6 to 70.0% in ICPR 2336 and ICPR 2904 compared to 64.8% in ICPL 332 and 86.0% in ICPL 87. The lines ICPR 2904, ICPR 2905, and ICPL 187-1 showed high susceptibility to wilt (>80% plant mortality) compared to 7.8% in improved version of ICPL 332 and 8.5% in ICPL 87.

HC Sharma and KB Saxena

Milestone 5A.3.1.2: Available male sterile (A/B) and fertility restorer (R) lines characterized using molecular markers (RKV/KML/KBS/DAH, 2009)

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/KML, 2009)

Hybrid pigeonpea technology is new and the efficiency of commercial hybrid production depends on the improved seed production technology. To reduce the cost of seed production of A-lines, an experiment was carried out by sowing ICPA 2048 at three spacings (75 × 30, 75 × 100, 75 × 150 cm). The results are awaited.

KB Saxena and K Madhavi Latha

Milestone 5A.4.1.2: A hybrid seed production manual published (KBS, 2006)

To guide scientists and seed producers involved in hybrid pigeonpea research and development a manual entitled "Hybrid Pigeonpea Seed Production Manual" was published in 2006. This manual contains the detailed information on various aspects of seed production technology of pigeonpea hybrids and their parents.

KB Saxena

Output Target 5A.5: 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_4 CMS system and its fertility restorers investigated (VD/KBS, 2007)

Transverse sections of young anthers from male-sterile and fertile plants showed no differences in the development of sporogenous tissues. The process of microsporogenesis was similar in both up to differentiation of PMCs into tetrad formation and differed thereafter. The PMCs of the male-sterile plants became shriveled due to breakdown of the tapetum layer, which not only gives support but also provides nutrition to PMCs. In the case of fertile plants, the process of microsporogenesis proceeded normally and all the layers of anther wall had developed by the time PMCs had formed. Unlike the male-sterile plants, the tapetum layer in the fertile plants was also found to be persistent till the development of pollen grains and subsequently ruptured to release the pollen grains.

Vijay Dalvi and KB Saxena

Milestone 5A.5.1.2: Genotype - environment interaction for the expression of male-sterility and fertility restoration assessed (KBS/VD/KML, 2009)

Stability of CMS lines: For commercial production of high-yielding hybrids, it is essential to identify stable CMS lines. Three CMS lines with diverse cytoplasm were selected for this study. These include ICPA 2067 (A_1 cytoplasm), ICPA 2052 (A_2 cytoplasm), and ICPA 2039 (A_4 cytoplasm). These lines were evaluated at Parbhani and Patancheru during 2004 and 2005 rainy seasons. The observations on pollen staining showed that ICPA 2039 was the most stable CMS line at both locations. In case of ICPA 2052, five out of 49 plants showed fertile pollen grains (5–30%) and the remaining plants were male-sterile at Patancheru. More or less similar results were observed at Parbhani. ICPA 2067 was found to be the most sensitive to the environmental changes, as 24 out of 28 male-sterile plants, reverted to male-fertility in winter months at Patancheru. At Parbhani also, 24 out of 36 male-sterile plants reverted to male-fertility.

Stability of fertility restoration: In general, the testers performed differently with regards to the fertility restoration of the three CMS lines. At Latur (18^{o}N), three testers (ICPL 129-3, BWR 23, and Nirmal 2) restored the male fertility of CMS line ICPA 2067, while BSMR 175 showed only 35% fertility restoration. The testers BDN 2, BSMR 736, and BSMR 853 showed >70% fertility restoration with ICPA 2067. These three testers can be purified to get 100% fertility restoration with ICPA 2067. Out of seven F_1 hybrids developed on ICPA 2052, three testers (ICPL 129-3, Nirmal 2, and BSMR 175) maintained complete male-sterility and four testers (BDN 2, BWR 23, BSMR 736, and BSMR 853) showed partial (60–80%) fertility restoration. The F_1 hybrids developed on ICPA 2039 showed that only ICPL 129-3 maintained complete male-sterility, while BSMR 736 restored complete fertility. The other five testers segregated for fertility restoration (66–85%). These testers can be purified to get 100% fertility restoration for development of hybrids. The results of the present study revealed that although there were differences among testers for fertility restoration of different cytoplasm, the genotype × environment interactions were not strong enough to influence selection and breeding of hybrids.

KB Saxena, Vijay Dalvi and K Madhavi Latha

Milestone 5A.5.1.3: New sources of cytoplasm identified and diverse CMS systems developed (KBS/NM/KML, 2010)

Crosses between diverse pigeonpea cultivars and wild species *Cajanus acutifolius* gave rise to F_1 hybrids. It was consistently observed that hybrids between pigeonpea cultivar ICPL 85010 and *C. acutifolius* ICCW 15613 gave rise to hybrids with high degree of male sterility. These hybrids were crossed with diverse pigeonpea cultivars to identify maintainers and restorers of male sterility. Cultivar 85010 consistently gave rise to progeny with high level of sterility (60–100 %).

Crosses between *Cajanus platycarpus* and *C. cajan* have given rise to progeny with variation for many desirable characters. One such character is a high degree of male sterility in the progeny when crossed with cultivar ICPL 85010. To test the proof of concept if the progeny belonged to the class of CMS, they were crossed with diverse parents including wild species *C. platycarpus*. The progeny from crosses with *C. platycarpus* gave rise to the progeny, all with 100% male sterility. This shows that *C. platycarpus* maintains male sterility in the progeny.

Nalini Mallikarjuna and KB Saxena

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 (KML/KBS/SP, 2011)

The main objective of breeding parental lines is to broaden genetic base of the restorers and maintainers. Such genetic diversification of hybrid parents will help in increasing the magnitude of heterosis. During 2006, a program on the diversification of parental line was initiated by making crosses among B-lines in a diallel mating scheme. The similar approach is being followed to improve restorer lines.

K Madhavi Latha, KB Saxena and Suresh Pande

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)

Concerted efforts were made to enhance the partnership base for hybrid pigeonpea research and development. During 2006, the number of members in pigeonpea hybrid parents' research consortium increased from 9 to 14. In addition, links were strengthened with NARS partners in India and China.

KB Saxena, CLL Gowda and S Pande

Milestone 5A.7.1.2: Seeds of elite parental lines, and hybrids multiplied and distributed to NARS and seed companies (KBS, annual)

In 2006, seed of six A-lines and three hybrids were multiplied at Patancheru. Among the A-lines, ICPA 2043 (0.91 ha), ICPA 2047 (0.50 ha), ICPA 2048 (0.030 ha) and ICPA 2092 (0.16 ha) were multiplied in isolation using 1 male: 4 female ratio. Similarly, hybrids ICPH 2438 (0.30 ha), ICPH 2671 (0.30 ha) and ICPH 2741 (0.32 ha) were multiplied in isolation using 1 male: 4 female rows.

During 2006, a total of 2114 hybrid pigeonpea seed samples were supplied to private seed companies, public seed sector and NARS in India and other countries. This includes 1069 samples of hybrids, 164 A/B-lines, and 881 fertility restorer lines.

KB Saxena

Milestone 5A.7.1.3: Technical information and public awareness literature developed and disseminated (KBS/HCS/SP, 2007)

A public awareness flyer 'Hybrid Pigeonpea–Seeds of Excellence' was prepared and widely distributed among researchers and seed producers. This flyer contains information on hybrid technology, characteristics of A/B and R-lines, performance of some heterotic hybrids, and training opportunities.

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/KML, annual)

A total of 35 persons from NARS and the private seed sector were trained at Patancheru in hybrid pigeonpea breeding and production technology.

KB Saxena and K Madhavi Latha

Milestone 5A.7.1.5: Molecular markers and genetic maps developed and exchanged with the scientific community (RV/DAH/ KML/HDU/NM/KBS, 2010)

Efforts have been initiated for molecular characterization of 25 male-sterile and 30 restorer lines through micro satellite and DarT markers. The leaf samples of these lines have been collected and DNA extracted. The molecular characterization work is in progress.

Rajeev Varshney, DA Hoisington, K Madhavi Latha,
HD Upadhyaya, N Mallikarjuna and KB Saxena

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 with associated knowledge and capacity building in SAT Asia

Sorghum and Pearl Millet

MTP Output Targets 2006:
Three sorghum varieties with greater tolerance to salinity identified and made available to partners

Six pearl millet hybrid parental lines and populations with superior tolerance to salinity identified and made available to partners

New pearl millet hybrid parents selected for salinity tolerance in pot culture available for field testing

New genetic variability in sorghum introgressed and new derivates less sensitive to terminal drought stress available to partners along with grain mold resistant hybrid parents

I. Sorghum

Output target 5B.1: At least five salinity-tolerant sorghum 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 breeding lines/populations developed/ identified (BVSR/VV, 2009)

Introgression of salinity-tolerance into high-yielding backgrounds: A total of 405 F_3s were produced from 139 F_2s derived from the crosses between salinity-tolerant breeding lines and high-yielding B-lines during the 2006 rainy season. Similarly, a total of 139 F_3s were produced from 54 F_2s derived from the crosses between salinity-tolerant breeding lines and high-yielding R-lines during the 2006 rainy season. These are being further advanced.

Comparative performance of hybrids for salinity tolerance: A trial of 30 hybrids along with three checks, viz, CSH 16, SP 40646 and ICSB 406 was conducted during 2006 rainy season at the Agricultural Research Station (ARS), Gangavathi to ascertain the salinity tolerance and grain yield in large grain backgrounds. Among them, 16 hybrids with a grain yield range of 4.8 to 6.0 t ha^{-1} were on par with the hybrid check CSH 16 (6.6 t ha^{-1}). For grain size, 25 hybrids with a range of 2.76 to 3.56 g 100^{-1} were comparable with the best check SP 40646 (3.22 g 100^{-1}) in the saline soil (10 dS m^{-1}) at ARS, Gangavathi.

BVS Reddy

Pot-culture trial of parental lines and hybrids: A total of 38 parental lines of sorghum were tested for salinity tolerance, along with 34 hybrids. There was a large variation among the lines for the grain yield ratio (grain yield salinity/grain yield control) ranging from 0.022 to 0.536, which is a proxy for salinity tolerance. Most of the accessions tested appeared to have low ratio, indicating that they were susceptible to salinity. Genotypes ICSB 405, ICSR 170, ICSR 93034, ICVS 93046, ICSV 745, GD 65115, SP 47513, SP 47519, SP 39105, SP 39053 had high ratios and were, therefore, tolerant to salinity. Regarding the stover yield ratio (stover yield salinity/stover yield control), most of the genotypes were in the range 0.40–0.80, showing much less contrast than for yield. There was no advantage of hybrids over parents in terms of stover yield ratio, which was slightly higher for inbreds than for hybrids (0.75). The grain yield ratio was also higher for inbred parents (0.20) than for hybrids (0.13). The same was true for the absolute values of yield under salinity conditions, with average across parents being higher (8.4 g $plant^{-1}$) than the hybrids (7.4 g $plant^{-1}$). Therefore, it was concluded that sorghum hybrids had no significant advantage compared to inbreds under saline conditions.

I. Salinity field trial of varieties: We tested promising salinity-tolerant sorghum breeding lines in coastal Orissa. There was a large range in adaptation of these genotypes to the area, and some varieties such as S 35, ICSV 112, ICSV 406, ICSR 170, ICSV 93034 were able to reach over 10 t/ha of green fodder yield in saline field over two cuttings. These data are very promising because it provides potential to have a crop grown after rice in a cropping system that usually leaves lands fallow after rice harvest, mostly because salinity levels rise during the postrainy season, which is too high for most crops. Repeat of this testing is planned for 2006–07.

Vincent Vadez, L Krishnamurthy and Belum VS Reddy

Milestone 5B.1.1.2: New F_6 RIL mapping populations for salinity tolerance available for phenotyping and genotyping (CTH/BVSR/VV, 2009)

From the screening in milestone of breeding lines and parental lines, several suitable parents have been selected and crosses will be made to develop new RIL for QTL mapping of salinity tolerance.

These crosses are:
- BTx 623 (tolerant) × ICSR 93024-1 (sensitive)
- ICSV 93046 (tolerant) × S 35 (sensitive)
- BTx 623 (tolerant) × S 35 (sensitive)
- SP 39105 (tolerant) × ICSR 93024-1 (sensitive).

Vincent Vadez and L Krishnamurthy

Milestone 5B.1.1.3: QTLs for salinity tolerance identified (VV/CTH, 2010)

Salinity screening of parents of existing mapping populations of sorghum: Ten parents (BTx 623, IS 18551, 296B, ICSV 745, PB 15881-3, PB 15520, B 35, E 36-1, N 13, IS 9830) were tested in 2005–06 for salinity tolerance to examine whether any of these could be used for QTL mapping of salinity tolerance. We found a good contrast for the grain yield ratio between E 36-1 (0.39) and N 13 (0.13), and also between PB 15220 (0.45) and ICSV 745 (0.10). However, we did not detect any significant contrasts for the stover yield ratios among the available pairs of parental lines.

V Vadez

Output target 5B.2: Identification of sorghum genotypes with contrasting root traits (2009)

Activity 5B.2.1: Stay-green QTL introgression lines tested for root traits (VV/CTH, 2009)

Milestone 5B.2.1: Putative relation between stay-green QTL introgression lines and root traits identified (VV/CTH, 2009)

Root traits of stay-green lines: A repeat trial with long (2.40 m) PVC pipes was done to evaluate root growth at different stages and under different timing of imposed stress, using 2 stay-green genotypes (B 35, E 36-1) and 2 senescent genotypes (R 16 and ISIAP Dorado). The purpose of the experiment was to determine the most suitable timing of stress imposition to identify differences, if any, in the rooting pattern. Stress was imposed at 21, 35, 49 and 63 days after sowing. For each date, fifteen plants per genotype were grown under well-watered conditions until the seedset date. At each date, 5 plants were used to assess their root characteristics at that date. Then 5 plants were exposed to water stress and the remaining 5 plants were kept under well-watered conditions. Water-stressed and well-watered plants were used at 42, 40, 37, and 26 days after stress imposition, respectively, for sets of plants treated at 21, 35, 49, and 63 days after sowing.

In the sets of plants that were stressed at 21 and 35 DAS, we did not find any root depth differences between stay-green and senescent genotypes at harvest (respectively at 63 and 75 DAS). By contrast, we found that when stressed at 49 DAS, both stay-green genotypes had deeper rooting systems than senescent R 16 and ISIAP Dorado (15–35 cm deeper). Also, the two stay-green genotypes had a larger proportion of roots in the deeper layers of soil than R 16. Overall, this experiment confirmed the earlier finding of a deeper rooting and more profuse rooting in deeper layers of stay-green genotypes compared to senescent materials, under conditions of water deficit. What appeared also from this experiment is that compared to control, there was little difference in the root distribution in the layers below 90 cm in water-stressed and well-watered R 16, whereas B 35 was able to allocate a much larger proportion of roots in deeper layers under water stress than under well-watered conditions. In this experiment, the shoot dry weight under water stress, expressed as a percentage of control well-watered plants, was also higher in B 35 and E 36-1 than in R 16.

Root traits of stay-green introgressed lines: RSG 04001 and RSG 04005 are BC_1F_3 and BC_2F_3 derivatives from B 35 in the background of recurrent parent R 16, whereas IDSG 04211 is a BC_2F_3 derivative from B 35 in the background of recurrent parent ISIAP Dorado. Fifteen plants of these genotypes were grown in PVC pipes as above and stress was applied from 21 days onwards. The plants were harvested at 60 DAS. In this experiment, similar to the one reported above, there was no difference in root depth between B 35 and R 16. By contrast, two of the promising derivatives (RSG 04001 and RSG 04005) had deeper rooting and more profuse rooting in the 120–150 cm layer than R16. In this experiment also, it was evident that, compared to well-watered plants, B 35, RSG 04001 and RSG 04005 were able to increase their deep rooting relatively more than R 16. Also, the shoot dry weight under water stress, expressed as a percentage of control well-watered plants, was higher in B 35 and RSG 04001 than in R 16.

Several conclusions and future orientations can be drawn from the different sets of experiments that have been carried out to investigate root traits in sorghum: (i) Stay-green donor parent B 35 and in some cases E 36-1, and derivatives from B 35 appear to have deeper rooting and more profuse rooting in deeper layers than R 16. However, these differences seem to be conditioned by the timing of stress imposition and duration of stress. Major differences between senescent and stay-green materials are found when stress is applied close to the reproductive period and/or when plants are exposed to water stress for a sufficient time; (ii) Though we found some differences, which tend to indicate a role of roots in the stay-green material, we have had difficulties to obtain significant results in all experiments, because of plant to plant variations and because of the fairly small differences in rooting traits; (iii) We have mostly assessed, so far, the parents of the stay-green trait, and have only recently started working with derivatives, which are showing promising results. There is a need to move forward and study the advanced backcross generations of these derivatives that have been produced from RSG 04001 and RSG 04005, the two promising introgression lines mentioned before; (iv) So far, we have assessed rooting characteristics. However, this does not give any indication on whether roots do contribute to a better water uptake. We observed that B 35 tended to senesce and dry later than R 16 under water stress, which would indicate that water uptake occurs for a longer period of time. Therefore, we are currently designing a lysimetric system, by which we could assess plant water uptake from the time of stress imposition. We believe that putative differences in the rooting characteristics would get integrated over time in larger differences for water uptake (easier to measure). If successful, such assay could eventually replace the time-consuming process of root extraction and its characterization.

Vincent Vadez and CT Hash

II. Pearl millet

Output target 5B.1: At least five salinity-tolerant improved 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)

Four yield trials consisting of 5−70 entries were evaluated at the Agricultural Research Station of the University of Agricultural Sciences at Gangavathi under saline field condition (10 dSm^{-1}). The data are awaited. A trial of 13 entries consisting of five parental lines (3 salinity tolerant and 2 susceptible) and 6 hybrids derived from them, along with two salinity-tolerant populations, was conducted under non-saline conditions at Patancheru to assess their yield potential. A hybrid (ICMA 01222 × ICMP 451) based on salinity-tolerant male and female lines had the highest grain yield (3400 kg ha^{-1}) and it flowered in 47 days, followed by another hybrid also based on salinity-tolerant parental lines (female parent ICMB 95333 and male parent ICMP 451) that had 3355 kg ha^{-1} of grain yield and flowered in 48 days. In comparison, the dual-purpose commercial hybrid ICMH 451 (based on salinity-tolerant male parent ICMP 451 and susceptible female parent 81B) had 3260 kg ha^{-1} of grain yield and flowered in 49 days. These two new hybrid, however had lower dry stover yield (3370 and 3320 kg ha^{-1}) compared to ICMH 451 (3850 kg ha^{-1}). Among the dwarf parental lines, ICMB 01222 had the highest grain yield (1970 kg ha^{-1}) and it flowered in 51 days compared to 1420 kg ha^{-1} of grain yield for 81B, which flowered in 54 days. However, 81B had 2490 kg ha^{-1} of dry stover yield compared to 1900 kg ha^{-1} for ICMB 01222.

KN Rai, Ranjana Bhattacherjee and Vincent Vadez

Pearl millet breeding line testing in farmer's field in Orissa: We have tested promising salinity-tolerant pearl millet parental breeding lines in coastal Orissa. There is a large range of adaptation of these genotypes to the area, and some accessions such as HHVBC Tall, Raj 171, IP 6105, IP 6106, IP 19586 were able to produce over 10 t ha^{-1} of dry fodder yield in saline field over two cuttings. These results are promising because they provide the potential to have pearl millet successfully grown in that transiently salinity-affected rice-based cropping system.

Vincent Vadez, L Krishnamurthy and KN Rai

Output target 5B.2: Putative QTLs for salinity tolerance of grain and stover yield identified in pearl millet (2009)

Activity 5B.2.1: Genotyping and phenotyping of mapping populations for salinity tolerance

Milestone 5B.2.1.1: Putative QTL for salinity tolerance based on 160 RILs from one mapping population identified (CTH/SS/VV, 2009)

Confirmation of the contrast for salinity tolerance between parents of pearl millet populations: Twenty parental lines of ten pearl millet mapping populations were tested for salinity tolerance, using the grain yield ratio as a selection criterion. This was a repeat experiment of the previous year, where 6 pairs of parents showed good contrast for the grain yield ratio. In the current trial, 4 pairs out of these 6 previously identified confirmed that trend.

Among these, pairs 1 (LGD 1-B-10 and ICMP 85410-P7) and 3 (863B-P2 and 841B-P3) appear more suitable for molecular marker identification, because of the large phenotypic differences and differences in marker polymorphism. However, based on the similarity in grain yield under control conditions (43.4 and 47.9 g $plant^{-1}$ for 841B-P3 and 863B-P2, respectively), and the large differences in their grain yields under salinity, the pair 841B-P3 and 863B-P2 appeared to be the most suitable. We also found two other pairs that showed contrasts for grain yield ratio.

The phenotyping of F_6 inbred progenies of the mapping population developed between 841B (tolerant) and 863B (sensitive) has been initiated and the harvesting is underway.

Vincent Vadez and CT Hash

Milestone 5B.2.1.2: Putative QTLs for salinity tolerance based on 35 BC_6F_3 contiguous segment introgression lines identified (CTH/SS/VV, 2010)

Funding to complete development of the contiguous segment introgression line set, and initiate its assessment, was received from DBT in December 2006, so work towards this milestone on this will recommence in 2007.

Milestone 5B.2.1.3: New F_6 RIL mapping populations for salinity tolerance available in pearl millet for phenotyping and genotyping (CTH/BVSR/KNR/VV, 2009)

The existing (ICMB 841-P3 x 863B-P2)-derived pearl millet mapping population was advanced to F6 RILs. The new RILs are being skeleton mapped as part of an exercise to create a more informative pearl millet consensus linkage map. Seed of approximately 150 progenies of this RIL mapping population are now available for salinity tolerance screening while new pearl millet RIL mapping populations are being generated for this target trait. Crosses were made between several selected pairs of sorghum parental lines exhibiting substantial pair-wise dissimilarity (>70%) at 67 SSR loci distributed across all 10 sorghum linkage groups, as well as substantial phenotypic differences for salinity tolerance based on pot screens of 30 candidate parental lines. F1 hybrids from several such crosses were sown for advance to the F2 generation by selfing during the 2006/07 postrainy season.

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)

QTL for improved grain yield across variable grain-filling moisture environments: Previous molecular work on drought tolerance in pearl millet has focused on QTL for the ability to maintain yield under post-flowering drought stress, which can be easily transferred to otherwise well-adapted hybrid parents to improve the performance of their hybrids under this type of stress. Pearl millet breeding programs targeting adaptation to variable post-flowering moisture environments would benefit from QTLs that improve grain yield across the full range of post-flowering moisture conditions, rather than in just some specific drought-stressed environments. We reanalyzed an extensive (12 environment) phenotyping data set that included both stressed and non-stressed post-flowering environments, to identify QTLs for improved yield over the whole range of moisture environments. Genetic materials were testcrosses of 79 F_2-derived F_4 progenies from a mapping population based on a widely adapted maintainer line (ICMB 841) × a post-flowering drought tolerant maintainer (863B). Three QTLs (on LG 2, LG 3, LG 4) were identified as primary candidates for MAS for improved grain yield across variable post-flowering moisture environments. QTLs on LG 2 and LG 3 (the most promising) explained a useful proportion (13 to 25%) of phenotypic variance for grain yield across environments. They also co-mapped with QTLs for harvest index across environments, and with QTLs for both grain number and individual grain mass under severe terminal stress. Neither had a significant QTL × environment interaction, indicating their predicted effects should occur across a broad range of available moisture environments. Finally, both are linked to SSR markers so they are amenable to efficient MAS. The remaining QTL (LG 4) is of secondary interest as it has a less consistent performance across individual moisture environments and a less clear effect on secondary traits. Responses to MAS predicted for each of the identified grain yield QTLs ranged from 70 to 100 kg ha^{-1} across environments and as much 160 kg ha^{-1} in individual moisture environments.

FR Bidinger, T Nepoleon and CT Hash

Improvement of the post-flowering drought tolerance of ICMB 841 by MABC: We completed the evaluation of 13 BC_5F_3 segmental introgression lines targeting the LG 2 QTL (for post-flowering drought tolerance) from 863B in the background of widely adapted seed parent ICMB 841. These segmentally near-isogenic lines were evaluated in testcross hybrid form (with both drought-tolerant and drought-susceptible testers) in multiple years in both the

Patancheru dry season drought nursery (where the LG 2 QTL was identified) and in natural drought-prone locations. B-line tolerance/sensitivity to post-flowering terminal drought stress was assessed by comparing B-line general combining abilities (GCAs) for grain yield in the stress and non-stress environments. The data set included three non-stress and seven post-flowering stress environments in the drought nursery and four naturally-stressed environments in western Rajasthan. The original recurrent parent ICMB 841 had a significant ($P<0.01$) negative grain yield GCA in the drought nursery stress environments and a non-significant GCA for grain yield in the non-stressed drought nursery environments, confirming its sensitivity to post-flowering stress, but not necessarily a lack of adaptation to the dry season environment *per se*. The QTL donor parent 863B had highly significant ($P<0.001$) GCAs for grain yield in both the stressed and non-stressed drought nursery environments, indicating that it is both adapted to the dry season environment and is tolerant to post-flowering drought stress. The best of the QTL introgression lines (ICML 03056) had a significant positive GCA under stress in the drought nursery and five others had non-significant positive GCAs for grain yield, indicating their superiority over their recurrent parent under stress. The remaining lines were similar to ICMB 841 (ie, sensitive to the stress). In the non-stress drought nursery environment, these lines had grain yield GCA values similar to ICMB 841, indicating that the effect of the LG 2 QTL was specific to the stress environment. None of the introgression lines had grain yield GCA values as high as the QTL donor parent 863B in either of the drought nursery environments. This was expected, however, as the original mapping exercise identified additional QTLs for post-flowering drought tolerance (with the positive allele from 863B) that were not transferred to the ICMB 841 background in this set of introgression lines. The significant improvement in the grain yield GCA of a number of the ICMB 841 QTL introgression lines, in the same stress environment in which the QTL was originally identified, provides a solid proof-of-concept of the effectiveness of MABC transfer of the LG 2 drought tolerance QTL to a drought-sensitive genetic background.

Of equal importance is the effectiveness of the LG 2 drought-tolerance QTL across a range of post-flowering stress environments, rather than just in the environment in which the QTL was identified. The testcross trials in the Rajasthan environments generally did experience post-flowering stress (often severe and early onset), but they were more variable than the managed drought nursery post-flowering stress environments. In addition, the donor and recurrent parents responded differently to the Rajasthan environments than they did to the drought nursery stress environments, as the grain yield GCA of 863B was negative ($P<0.01$) and that of 841B was not significant. Part of this was due to the 863B testcrosses flowering later than those of 841B, which placed them at a significant yield disadvantage, as there were very strong negative correlations between time to flowering and grain yield in all of the Rajasthan test environments ($r = -0.73$ to -0.98, $P<0.01$). We adjusted testcross grain yield (by covariance) for time to flowering, in order to separate the effects of drought escape (early flowering) and drought tolerance/sensitivity, and recalculated grain yield GCA on the adjusted values. Despite this, the GCA for grain yield of the individual QTL introgression lines varied considerably among the individual Rajasthan environments, with the result that mean GCA values for grain yield across environments were not significantly different from zero for either ICMB 841 or any of the QTL introgression lines (although the mean grain yield GCAs of several lines were positive and numerically superior to that of ICMB 841). The drought-tolerance QTL on LG 2 was detected based on the measurement of grain yield under stress in the drought nursery. Grain yield is typically subject to significant GE interaction, so the discrepancy in the effect of the QTL in the drought nursery and the arid zone evaluation environments, while disappointing, is not an anomaly. Yield-based drought tolerance QTL will clearly need to be identified either in the target environment, or in an environment that is sufficiently similar to the target environment so that the GE interaction between the two is minimal.

P Sathish Kumar, FR Bidinger and CT Hash

Milestone 5B.3.1.2: DM resistance and terminal drought tolerance QTLs pyramided in the genetic background of elite pollinator H 77/833-2 and QTL introgression homozygote product lines available for testing (CTH/PSK/SS/VV/ RPT/RS/KNR, 2007)

To be reported in 2007

Output target 5B.4: Pearl millet germplasm with superior P-acquisition identified (2009)

Activity 5B 4.1: Development of an effective protocol and identifica-tion 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)

Large efforts have been dedicated in 2005 and 2006 to develop an efficient and reproducible protocol to test the response of pearl millet genotypes to low P availability under controlled conditions. 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 observations that growing 3 plants per replicate pot helps in decreasing the replicate-to-replicate variation. We are also aware of a genotype by 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 out that small differences 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).

Vincent Vadez

Milestone 5B.4.1.2: Pearl millet germplasm with superior P-acquisition from low-P sources identified (VV, 2009)

We have initiated the assessment of two pearl millet open-pollinated varieties (OPVs) (ICMV IS 92222 and ICMV IS 89305) for their ability to acquire P from low-P soils. In a controlled pot experiment using the protocol described above, we have found a 2-fold variation for biomass under low-P in 184 S_1 progenies. The top and bottom 25 S_1s for shoot biomass under low-P conditions have been planted to generate full-sibs of the top and bottom ranked. These will be selfed for one generation and S_1s will be evaluated in 2007.

Vincent Vadez and KV Padmaja

Milestone 5B.4.1.3: QTL for P acquisition from low-P sources identified in pearl millet (VV/CTH, 2011)

The parents of existing mapping populations of pearl millet have been tested for their ability to acquire P from low-P sources. Consistent contrast has been found between 2–3 pairs of parents. We have found that the shoot biomass under low-P conditions was well correlated to the shoot biomass under controlled conditions, meaning that low-P tolerance may be better assessed by the ratio biomass under low-P / biomass under control. However, differences found with in mapping population parents were relatively small. Larger number of inbred parents will be tested to identify the most contrasting pairs for developing new RIL populations.

Vincent Vadez

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 glasshouse conditions validated (KNR/RB/VV, 2009)

Heat-tolerant hybrid parents: 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. A few of the hybrids, however, set excellent seeds, indicating genetic variability for thermo-tolerance during the reproductive stage. With the assistance of MAHYCO, 92 maintainer lines (B-lines) and 7 restorer lines (R-lines) were evaluated for seed set under open pollination in a summer planting at Jodhpur. Most of the lines either did not set, or had <1% seed set under open-pollination. However, 30–60% seed set was observed in at least one plant in six B-lines (ICMB 96222, ICMB 00333, ICMB 01555, ICMB 03555 ICMB 04333, and ICMB 05333) when the air temperature was 46–48^{0}C at the time of stigma emergence, indicating high levels of thermo-tolerance and variability for this trait within these lines. Ten plants were selfed within these lines during the 2006 rainy season to derive single plant progenies that will be evaluated during the 2007 summer season at Jodhpur to confirm the within-line variability for this trait and to make selection for higher levels of thermo-tolerance.

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)

In the first evaluation attempt, six lines with 30–60% seedset at 46–48°C air temperatures have been identified, with indication of within-line variability for this trait. The purification of these lines for this trait was initiated, and plans were developed to screen more lines for thermo-tolerance. Lines with confirmed high levels of tolerance will have been identified by 2008, and the research on the relationship between parental lines and their hybrids will start in 2009.

KN Rai, Ranjana Bhattacharjee and V Vadez

Salinity trial: A trial was conducted with hybrids made utilizing salinity tolerant and susceptible male sterile lines and restorer lines, including their parents along with two salinity tolerant populations as checks (GB 8735 and HHVBC Tall) during rainy season at Patancheru location. All the hybrids flowered in 47–49 days (checks GB 8735 flowered in 45 days and HHVBC Tall in 51 days). None of the hybrids produced significantly superior grain and dry fodder yields over the checks. However, two hybrids, ICMB 95333 × ICMB 94111 and ICMA 01222 × ICMP 451 gave comparable grain yields of 3413 kg ha^{-1} and 3400 kg ha^{-1} respectively, as that of check HHVBC Tall (2958 kg ha^{-1}). Only one hybrid ICMH 451 gave comparable dry fodder yield of 3850 kg ha^{-1} as that of check GB 8735 (3270 kg ha^{-1}). This indicates that hybrids with either one both the parents, tolerant to salinity will give higher grain yields when compared to hybrids produced by involving susceptible parents.

Hybrid and parental lines of pearl millet (Exp1-2-3-4-5)

A set of tolerant and sensitive inbred parents, along with their respective hybrids were tested under saline controlled conditions. The large pot system allowed us to evaluate grain and stover yield at maturity. There was no clear relation between the performance of the hybrids and the performance of its parents. Overall, hybrids performed better under salinity, reaching an average grain yield of 19.8 g $plant^{-1}$, higher than an average 12.2 g for the inbreds/populations. In fact, we found a very close correlation (r^2 = 0.69) between the grain yield under control and the grain yield under salinity. This meant that a lager part of the grain yield under salinity was explained by yield potential. The yield data were then separated into yield as a component and a residual (the latter accounting for the salinity tolerance *per se* plus error. These residuals were well related to the grain yield ratio (grain yield under salinity/grain yield under control). So, both grain yield ratio and residual were used to assess salinity tolerance. The yield ratio was not significantly different for the hybrids and the inbreds/populations (0.38 and 0.36, respectively). There were no differences in residuals of hybrids and inbreds/populations either, indicating that hybrid performance under salinity was likely to be largely due to their yield potential, but partly due to salinity tolerance as well, the latter not being any greater in hybrids than in the parental lines.

Vincent Vadez, L Krishnamurthy and KN Rai

Milestone 5B.5.1.3: QTL for high temperature tolerance from two diverse mapping populations identified (KNR/RB/VV, 2012)

Based on the results of activities under above milestone 5B.5.1.2, parental lines of mapping populations will have been identified by 2009.

KN Rai, Ranjana Bhattacharjee and Vincent Vazed

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

MTP Output Target 2006: Existing hybrid parents in sorghum having grain density of Zn above 25 ppm and Fe above 30ppm available to partners

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 (BVSR/HDU, 2008)

Core collection evaluation for micronutrient density

A large number of germplasm accessions (2974) from the core collection of sorghum were evaluated for accessing genetic variability for grain Fe and Zn contents. As core germplasm captures most of the variability present in world collection (>37000) maintained at ICRISAT, the information on the genetic variability would enable identifying micronutrient-rich lines for use in crossing with agronomically elite lines to generate exploitable variability to develop micronutrient-dense cultivars and hybrid parents. It would also enable identifying contrasting parents for effecting crosses to identify transgressive segregants and to develop mapping populations for identifying molecular markers linked to loci controlling grain Fe and Zn contents.

The core collection along with four control lines known for their Fe and Zn contents were evaluated in an augmented design at ICRISAT, Patancheru in 2005 postrainy season. For the sake of convenience, 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 along with 4 checks (repeated 11 times); the medium group comprising 1128 accessions along with 4 checks (repeated 12 times); and the late group comprising 751 accessions along with 4 checks (repeated 8 times). Each accession was sown in one row of 2 m length. In each accession, the border plants were left for open-pollination and all others were selfed. The 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, and presence/absence of seed sub-coat. Grain samples from some of the accessions could not be collected due to severe bird damage. In a few accessions, the available grains were not sufficient for estimation of Fe and Zn contents. 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), and the grain samples harvested from open-pollinated panicles of 118 accessions of early maturity, 69 accessions of medium maturity, and 21 accessions of late maturity (making a total of 208 accessions) where sufficient quantities were available processed and sent to ICRISAT's analytical services laboratory for grain Fe and Zn contents estimation.

A large variability for grain Fe (7.7 ppm to 132.6 ppm) and Zn (15.1 ppm to 91.3 ppm) was observed among the 1401 accessions. The variability observed in core collection is much higher than that reported earlier, based on screening of 86 genotypes consisting of germplasm lines, hybrid parents of released/marketed hybrids and popular varieties. Interestingly, white grain accessions used for human consumption in India had on an average 43.6 ppm Fe and 35.1 ppm Zn which was marginally higher than those with colored grains (40.4 to 42.6 ppm Fe and 30.9 to 34.0 ppm Zn). The average Fe and Zn contents of accessions with testa (42.5 ppm Fe and 34.2 ppm Zn) and without testa (42.9 ppm Fe and 33.2 ppm Zn) were comparable. However, endosperm texture and grain size have significant effects on grain Fe and Zn contents. While the accessions with higher than 75% corneous endosperm had 56.2 ppm Fe and 44.3 ppm Zn contents, those with 0% to 75% corneous endosperm had less than 44.8 ppm Fe and 35.0 ppm Zn. The texture of endosperm has significance in food preparations. While grains with 50% corneous endosperm are useful for preparation of *'roti'* or *'chapati'* (unleavened bread), the most popular food forms of sorghum grains in India; and for 'ingera' (leavened bread), the most popular food forms of sorghum grains in some parts of Africa, those with more than 75% corneous endosperm are useful for the preparation of '*to*' the most popular food form of sorghum grains in some parts of Africa. Accessions with small grains (with <2.5 g 100-grain weight) had significantly higher grain Fe (44.4 ppm) and Zn (35.9 ppm) contents than those with medium (with <2.5 g to 3.5 g 100-grain weight) (42.6 ppm Fe and 33.5 ppm Zn) to large (with >3.5 g 100-grain weight) grains (40.8 ppm Fe and 32.2 ppm Zn).

BVS Reddy, HD Upadhyaya and KL Sahrawat

Milestone 5C.1.1.2: Correlations of grain Fe and Zn contents with grain yield and size and agronomic traits estimated (BVSR, 2008)

Correlations of grain Fe and Zn contents with agronomic and grain traits in 1394 core germplasm lines were estimated. Fairly higher correlation ($r = 0.6$) between grain Fe and Zn contents suggests ample scope for simultaneous improvement of both the micronutrients in sorghum. Though correlation of grain Fe and Zn contents with days to 50% flowering (0.1 for Fe and 0.2 for Zn), plant height (0.2 for Fe and 0.4 for Zn) is significant and positive, the lower magnitude of the correlation suggests near independence of the crop growth traits and grain micronutrients contents. The results indicate that sorghum grain Fe and Zn contents can be improved in different maturity and plant stature backgrounds. Similarly, significant negative but lower magnitudes of correlation of grain Fe and Zn contents with grain yield (-0.2 Fe and -0.2 Zn) and grain size (-0.1 Fe and -0.1 Zn) suggest that it is possible to enhance grain Fe and Zn contents in high-yielding backgrounds with large grains.

BVS Reddy

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 soil micronutrient fertilization on sorghum grain micronutrient contents, a set of selected 12 sorghum lines (including hybrid seed parents, restorer lines and popular varieties) contrasting (high and low) for grain Fe and Zn contents were grown in vertisols (medium black soil) and alfisols (red sandy loam soils) with a combination of five different levels of micronutrients in 2005 postrainy season. To rule out the possible confounding effect of deficiency (as is true in experimental field soils of ICRISAT) of other micronutrients such as boron (B) and sulphur (S), Fe and Zn fertilization was combined with recommended levels of boron and sulphur. The five fertilization levels were-first level (T_1): recommended NPK + zero micronutrients; second level (T_2): recommended NPK + recommended Fe @ 10 kg ha^{-1}; (T_3): recommended NPK + recommended Fe @ 10 kg ha^{-1} + recommended S @ 30 kg ha^{-1} + recommended B @ 0.5 kg ha^{-1}; fourth level (T_4): recommended NPK + Zn @ 10 kg ha^{-1} + recommended S @ 30 kg ha^{-1} + recommended B @ 0.5 kg ha^{-1}; and fifth level (T_5): recommended NPK + Zn @ 10 kg ha^{-1} (Table 3). The experiment was laid out in strip-plot design with three replications. The data were collected on plant growth traits such as days to 50% flowering, plant height, 100-grain weight, grain color, panicle shape, panicle compactness, glume color, glume coverage, grain color, presence/absence of seed sub coat and grain yield. Hand threshed selfed seed samples from each entry grown at each fertilizer level and each replication were analyzed for grain Fe and Zn contents in soil chemistry laboratory at ICRISAT, Patancheru.

The analysis of variance (ANOVA) indicated significant mean squares due to genotype and first-order interaction of genotype with soil type and second-order interaction of genotype with soil type and different micronutrient fertilization levels for grain Fe and Zn contents as expected. While soil type did not have significant effect on grain Zn content of the test sorghum lines, it did have significant effect on grain Fe content. Interestingly, non-significant variance due to micronutrient fertilization levels per se suggested poor evidence on the influence of soil micronutrient fertilization on grain Fe and Zn contents in any particular soil type. However, significant mean squares due to interaction of micronutrient fertilization levels with soil type indicated that grain Zn content (but not Fe content) of the genotypes varied with a given combination of micronutrient level and soil type.

The ANOVA indicates only overall trend in variation of lines for grain micronutrient contents as influenced by micronutrient fertilization, and it does not reveal pattern of variation when pair-wise fertilization level effects are examined. For example, mean performance of the lines at different fertilization levels indicated that grain Fe and Zn contents were significantly higher without micronutrient fertilization compared those with both Fe and Zn fertilization per se or in combination with boron and sulphur. However, there were no differences in grain Fe and Zn contents of the lines grown in any of the micronutrient levels. It appears that micronutrient fertilization does not influence the grain micronutrient contents. The results are based on single year and single location data with rather smaller plot size. Further experimentation is needed to confirm these results.

BVS Reddy, HD Upadhyaya and KL Sahrawat

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)

Selfed seed of a total of 12 lines contrasting for grain Fe content consisting of six core germplasm lines (>74 ppm) and six breeding lines (<25 ppm); and 12 lines contrasting for grain Zn content comprising of six core germplasm lines (>57 ppm) and six breeding lines (<15 ppm) were selected and planted in 2006 postrainy season for effecting crosses in half-diallel mating design. The F_1s derived from half-diallel crosses along with parents will be evaluated for investigating the inheritance of grain Fe and Zn contents.

BVS Reddy

Milestone 5C.1.2.2: F_6 RILs from at least one cross developed (BVSR/CTH, 2009)

Two best half-diallel crosses involving the most contrasting parents for Fe and Zn contents will be used to derive recombinant inbred lines (RILs).

BVS Reddy

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 mg kg^{-1}) and Zn (45–55 mg kg^{-1}) 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 Fe and Zn content of designated hybrid parents: Evaluation of a limited number of designated seed parents in an earlier study showed some of these having high levels of grain Fe and Zn contents. Thus, we screened 99 seed parents and 93 restorer parents for Fe content, using the Perls Prussian Blue staining method to get a preliminary assessment of the variability for Fe content. Open-pollinated grains, produced for 1000 grain-mass data that were collected as a part of their characterization for DUS (Distinctness, Uniformity, Stability) database, were used for Fe analysis. Of the 99 seed parents, 29 seemed to have high Fe content (18 with deep blue and 11 with medium blue stain). Of the 93 restorer lines, 23 lines seemed to have high Fe content (10 with deep blue color and 13 with medium blue color). Since there is large variability among the lines both within the B-line and R-line sets, these will be further subjected to laboratory analysis to obtained quantitative estimates of the Fe and Zn contents.

Intra-population variability for Fe and Zn content: A total of 64 S_3 progenies previously derived from a released variety in India, AIMP 92901, and 68 S_2 progenies from another released variety in Africa, GB 8735, that had been identified for high Fe and Zn from the set 1 trial, were field tested during the 2005 rainy season and 2006 postrainy season to determine the intra-population variability. The correlation between two seasons for Fe ($r = 0.75$ in AIMP 92901 and $r = 0.60$ in GB 8735) and Zn content ($r = 0.80$ in AIMP 92901 and $r = 0.64$ in GB 8735) was highly significant ($P<0.01$) and positive. Hence, the mean over the seasons were considered for analysis. Highly significant differences were observed among the progenies for both micronutrients, 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 two-season data, approximately three-fold variation for grain Fe content in AIMP 92901 (40.9 to 118.9 mg kg^{-1}) and in GB 8735 (45.5 to 108.3 mg kg^{-1}), and two-fold variation for grain Zn content (31.8 to 82.7 mg kg^{-1} in AIMP 92901 and 33.8–70.5 mg kg^{-1} in GB 8735) was observed (Figs. 1 and 2). There was highly significant ($P<0.01$) and positive correlation between Fe and Zn in progenies of AIMP 92901 ($r = 0.75$) and GB 8735 ($r = 0.77$).

Fifty progenies, derived from each of the four additional populations (CGP, GGP bulk, ICTP 8203 and PVGGP 6) that were identified for high Fe content in a previous trial in 2004 rainy season were evaluated during the summer and rainy seasons 2006. Results of the summer season grain analysis showed significant differences among the S_1 progenies of ICTP 8203 and CGP. The remaining two populations (GGP Bulk and PVGGP 6) are yet to be analyzed. Approximately two-fold variation was observed for both grain Fe and Zn content in both ICTP 8203 (55.3–138.2 mg kg^{-1} Fe and 38.9–106.7 mg kg^{-1} Zn) and CGP (64.4–150.7 mg kg^{-1} Fe and 57.9–99.6 mg kg^{-1} Zn) (Figs. 3 and 4). Nine progenies of ICTP 8203 and 23 of CGP population had grain Fe content in excess of 100 mg kg^{-1} (100.3–150.7 mg kg^{-1}); and 10 progenies in each of the two populations had grain Zn content in excess of 80 mg kg^{-1} (80.5–106.7 mg kg^{-1}). There was highly significant ($P<0.01$) positive correlation between Fe and Zn content ($r = 0.78$ in ICTP 8203 and $r = 0.74$ in CGP).

About 100 S_1 progenies have been produced from each of the four populations (CGP, GGP bulk, ICTP 8203 and PVGGP 6). Based on the laboratory results available for all the populations, progenies of the two populations having the highest levels of Fe and Zn will be field tested and the grains produced will be analyzed for the Fe and Zn content. About 100 S_1 progenies were also produced from another five populations (Ugandi, Higrop, PVGGT-5, IAC-ISC-TCP 4 and ICMV-IS-94206) for Fe and Zn analysis.

KN Rai and KL Sahrawat

Milestone 5C.1.1.2: Variability for Fe and Zn in iniari germplasm, core collection and commercial hybrids assessed (KNR/RB/HDU/KLS, 2008)

Search for high grain Fe and Zn content in *iniari* germplasm

Grains of 313 *iniari* germplasm accessions along with two checks (ICTP 8203 and ICMR 356) were produced during the 2006 postrainy season for grain Fe determination using Pearls Prussian Blue staining method. Of these, 99 germplasm accessions had deep blue color and 62 had medium blue color. The accessions showing medium to deep blue color flowered in 37–58 days. Based on visual assessment of agronomic traits, 60 accessions were selected, producing 76 S_1 progenies. These were evaluated during the 2006 rainy season, and 50 progenies were selected, of which 4 flowered in 41–45 days and 39 flowered in 46–55 days and (check ICTP 8203 flowered in 46 days). More than 100 S_2 progenies were generated from the selected progenies for further evaluation and utilization in breeding large-seeded hybrid parents.

Evaluation of core collection for grain Fe and Zn content: Since iniari germplasm is genetically more related, 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-iniari groups of materials. A core collection of 504 accessions from 25 countries was screened using the Perls Prussian Blue staining technique on a 1–4 scale (1 = no color; 2 = less intense blue color; 3 = medium blue color and 4 = deep blue color) to identify those with scores 3 and 4. There were 117 accessions each in the deep and medium-blue color stain, indicating that about 46% of accessions in core collection have medium to high Fe content. These will be field grown for grain production and laboratory analysis of the grain Fe and Zn content.

KN Rai, HD Upadhyaya and KL Sahrawat

Milestone 5C.1.1.3: G × E interaction for Fe and Zn assessed and lines stable for >70 mg kg^{-1} Fe and >50 mg kg^{-1} Zn identified (KNR/RB/KLS, 2009)

Stability of grain Fe and Zn content: Twenty-eight entries representing a wide range of Fe and Zn content and selected from a 120-entries trial conducted for two seasons along with a check OPV (WC-C 75) were further evaluated during the summer and rainy season of 2005 and the summer season of 2006 for stability of these micronutrients. Grain Fe and Zn data from these five trials were subjected to stability analysis following Eberhart and Russell model. Highly significant ($P<0.01$) differences were observed among entries, among environments, and for entries × environment interaction, both for the Fe and Zn content. 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.
The mean grain Fe content of lines varied from 33.3 to 82.6 mg kg^{-1} and that for Zn it varied from 28.6 to 64.3 mg kg^{-1}. All except three entries were stable both for Fe and Zn. Incidentally, a S_4 progeny from AIMP 92901 had the

highest levels of both Fe and Zn, with unit regressions and non-significant deviations from regression both for Fe and Zn., indicating it the most stable line. Seed parent 863B, found to be drought-tolerant, high general combiner for grain yield, and highly resistant to multiple pathotypes of DM, had the next highest level of Fe (71.9 mg kg^{-1}) and had 53.1 mg kg^{-1} of Zn content. This line was also highly stable for both Fe and Zn content.

This stability trial was sent to nine diverse locations in different agro-ecological conditions in India under the ICAR-ICRISAT partnership project to further investigate the stability of these lines for grain Fe and Zn content. Also, based on two seasons' data of a 69-population trial, 18 populations with diverse grain Fe and Zn density were identified for their stability evaluation.

KN Rai

Output target 5C.2: Information on genetics and recurrent selection efficiency for grain Fe and Zn available (2009)

Activity 5C2.1: 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)

Genetics of grain Fe and Zn content: Recent research has identified several pearl millet breeding lines with high levels of gain iron (Fe) and zinc (Zn) content, and large variability for these traits in the improved breeding lines and populations. Utilization of this variability in breeding hybrid parents and populations with enhanced levels of these micronutrients can be more effective following efficient breeding methodologies based on the nature of inheritance. Genetics of these traits has not been reported so far in pearl millet. In an initial attempt in this direction, 10 inbred lines with a wide range of Fe and Zn contents were crossed in a diallel fashion (including reciprocals). The resulting 90 F_1s and 10 parents were evaluated during 2005 rainy season and 2006 summer seasons. Sib-mated grains were used for laboratory analysis of grain Fe and Zn content using dry ashing and Atomic Absorption Spectrophotometry method at the National Institute of Nutrition, Hyderabad.

Entry × season interaction was significant, but it was of negligible order. Reciprocal effect was non-significant for both grain Fe and Zn content. Therefore, means over the reciprocal crosses and the seasons were subjected to half-diallel analysis. The genetic component analysis indicated absence of epistasis for both traits, the Wr-Vr graph revealed presence of partial dominance for grain Fe and Zn content. The predictability ratio measured by $2\sigma^2gca/(2\sigma^2gca + \sigma^2sca)$ was around unity for both grain Fe (0.86) and Zn content (0.88), implying preponderance of additive gene action. Also, there was highly significant positive correlation between the mid-parental values and mid-parent heterosis ($r = 0.79$; $P<0.01$ for Fe and $r = 0.81$; $P<0.01$ for Zn), which was an additional indication of the predominant role of additive gene action for these traits. The grain Fe and Zn content in parents were highly correlated with their *gca* effects ($r = 0.92$; $P<0.01$ for Fe and $r = 0.94$; $P<0.01$ for Zn). The average heterosis was negative and negligible both for grain Fe (-6.1%) grain Zn content (-2.1%). In general, the high grain Fe and Zn contents in parents were governed by recessive alleles with increasing effects and the low contents were due to excess of dominant alleles with decreasing effects. The correlations between the performance *per se* of the inbred lines and their general combining ability (GCA) were positive and highly significant both for Fe ($r=0.79$) and Zn ($r=0.81$), indicating that selection of lines with high levels of these micronutrients will be highly effective in selecting lines with high GCA for these traits.

KN Rai

Milestone 5C.2.1.2: Effectiveness of S_1 recurrent selection for Fe and Zn, and its effect on grain yield and other agronomic traits in four populations quantified (KNR/RB/KLS, 2012)

Recurrent selection for high Fe and Zn content: Nine progenies with high grain Fe and Zn content were selected separately from AIMP 92901 (81.5−104.0 mg kg-1 Fe and 57.0−68.0 mg kg-1 Zn) and GB 8735 (78.5−104.5 mg kg-1 Fe and 57.0−59.5 mg kg-1 Zn), and random mated in 2006 summer to initiate recurrent selection. The C1 cycle bulks and original bulks of both the populations were evaluated in four replications during the 2006 rainy season and grains were produced for the laboratory analysis.

KN Rai and KL Sahrawat

Milestone 5C.2.1.3: QTL for high grain Fe and Zn identified based on F_6 RIL mapping populations from two crosses (CTH/SS/KNR, 2010)

Plant x plant crossing of five pairs of candidate parental lines, was followed by head-to-row advance of the F1 hybrids and their parents. Phenotypic assessment of Fe and Zn grain density of the parental lines, accompanied SSR marker polymorphism assessment of the parents, and visual assessment of the F1 progenies and selfed progenies of their parental plants, resulted in identification of four candidate populations from which F6 RIL populations can be derived to map these traits in pearl millet, and two of these have been chosen for generation advance during 2007

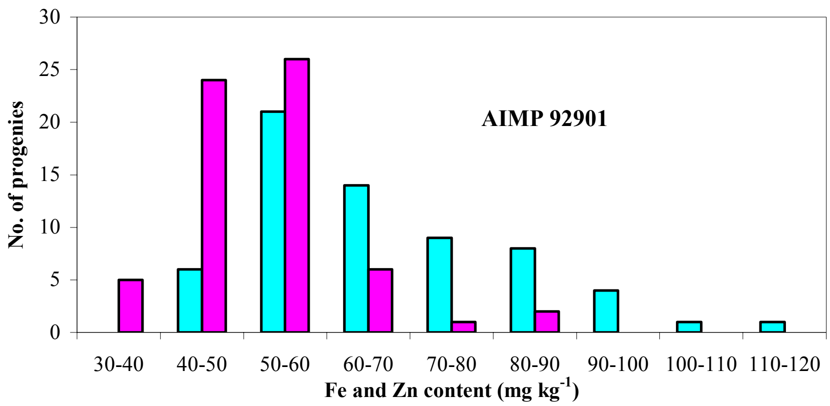

Figure 1. Frequency distribution of AIMP 92901 (S_3) progenies for grain Fe and Zn content, 2005 rainy and 2006 summer season, ICRISAT, Patancheru.

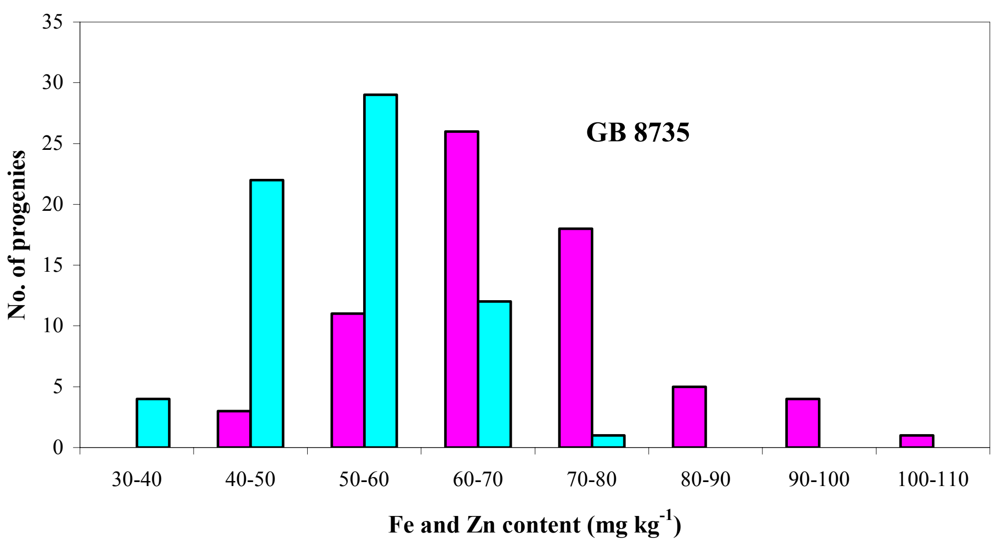

Figure 2. Frequency distribution of GB 8735 (S_2) progenies for grain Fe and Zn content, 2005 rainy and 2006 summer season, ICRISAT, Patancheru.

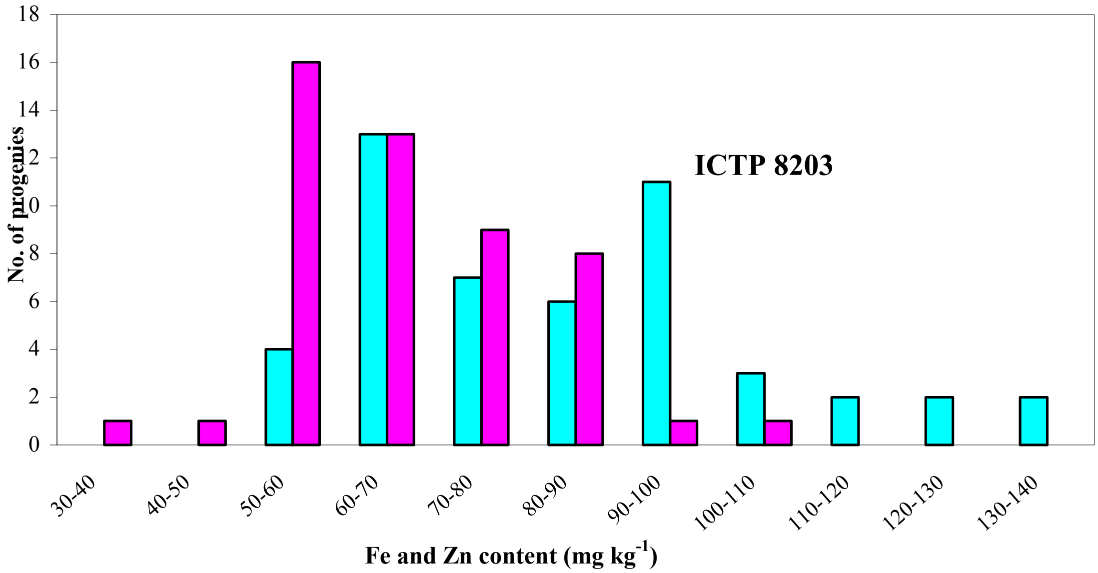

Figure 3. Frequency distribution of ICTP 8203 (S_1) progenies for grain Fe and Zn content, 2006 summer season, ICRISAT, Patancheru.

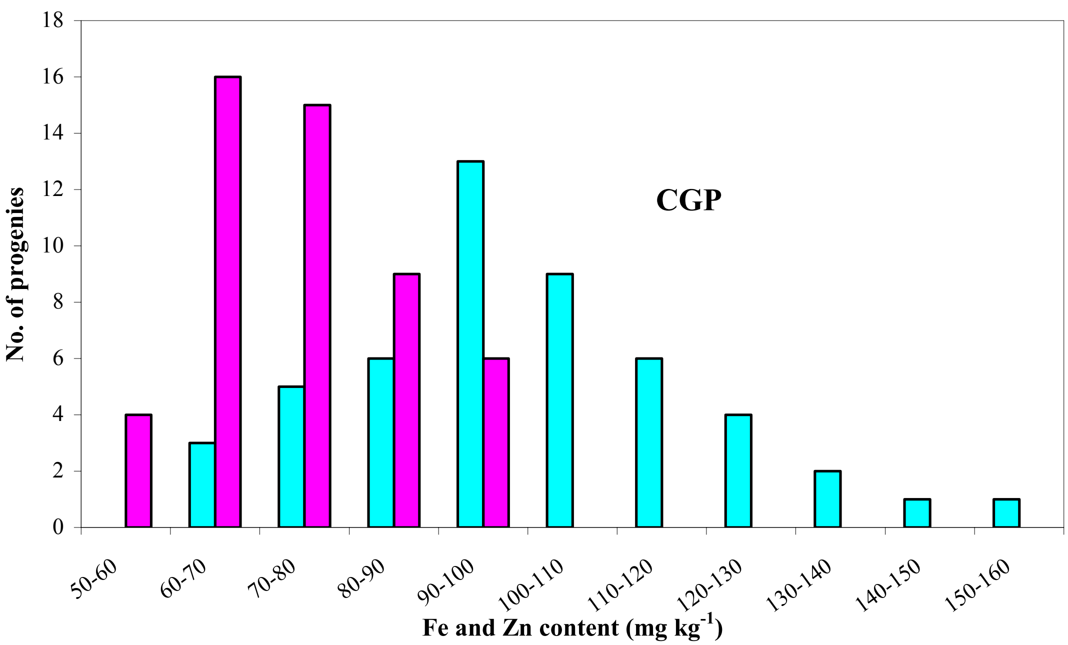

Figure 4. Frequency distribution of CGP (S_1) progenies for grain Fe and Zn content, 2006 summer season, ICRISAT, Patancheru.

Evaluation of sorghum and pearl millet for mycotoxins

Sorghum and pearl millet are staple food for millions of poor people in India, and they are important raw material in food and feed processing industry. These crops are affected by several fungi, causing grain molds (GM) that deteriorate grain quality. Some GM fungi can produce toxic metabolites, termed as mycotoxins, in grains that are hazardous to human and animal health. Of various grain molds, aflatoxins produced by *Aspergillus* species and fumonisins produced by *Fusarium* species are most frequent contaminants in sorghum and pearl millet. To enhance the quality of the grain by mitigating mycotoxin contamination through improved production technologies, participatory on-farm trials were conducted in Maharastra and Andhra Pradesh states, India, and grain samples from these trials were collected for mycotoxin analysis to assess the effect of improved varieties and cultural practices on mycotoxin contamination. A total of 440 sorghum grain samples were collected from 88 farmer fields from 5 villages (Udityal, Kakarjala, Veerannapalli, Rangampalli and Bandapalli) and they were analyzed for aflatoxins and fumonisin B1 by enzyme-linked immunosorbent assay (ELISA).

Aflatoxin contamination in sorghum samples collected from Udityal ranged from 0 to 561 μg kg^{-1}. Samples from 12% of the fields contained high levels of aflatoxins; lowest toxin levels (0–4.2 □g kg^{-1}) were found in samples from Rangampalli. In remaining villages, aflatoxin ranged between 0 and 48 □g kg^{-1}. Majority of the samples tested had toxins under permissible levels of 30 □g kg^{-1}; 28.4% samples had no detectable levels of aflatoxins; in 50.7% it was between 1 and 5 □g kg^{-1}; in 14.1% samples it ranged between 5 and 30 □g kg^{-1}; and 3.2% and 3.6% of the samples had 30.1−100 and 100.1−561 □g kg^{-1} aflatoxins. Fumonisin contamination in sorghum samples ranged from 0 to 1356 μg kg^{-1} with samples from 8% of the fields containing >100 μg kg^{-1}. Eighty-one percent of the individual sorghum samples were free from fumonisin contamination and 7% contained >100 μg kg^{-1} fumonisin.

Pearl millet samples (505) collected from 101 farmers' fields from six villages (Palavai, Peddapalli, Pavanampalli, Parmal, Kuruvupalli, Kondapalli) were analyzed for aflatoxins and fumonisin. Aflatoxin contamination ranged from 0 to 1047 μg kg^{-1}. Samples from 16% of the fields contained >30 μg kg^{-1}. In Pavanampalli, Parmal, Kondapalli villages, 29–38% fields contained >30 μg kg^{-1} aflatoxin. To our knowledge, this is the first record of high levels of aflatoxin contamination in pearl millet. Fumonisin contamination in pearl millet ranged from 0 to 186 μg kg^{-1} and only 1% of the samples collected from various farmers fields contained >100 μg kg^{-1}.

A field day was organized at Palavai village (Mahbubnagar district, Andhra Pradesh, India) to disseminate the technologies for improved productivity of crops and mitigate grain mold contamination in sorghum and millet. More than 200 participants (farmers and NGOs) participated in the field day.

Farid Waliyar

Project 6

Producing more and better food at lower cost of staple open-pollinated cereals and legumes (sorghum, pearl millet, pigeonpea, chickpea and groundnut) through genetic improvement and crop management in the Asian SAT

Groundnut

Output A: Improved germplasm and varieties of sorghum, pearl millet, pigeonpea, chickpea, and groundnut with pro-poor traits and advanced knowledge of selection tools and breeding methods made available to partners internationally

MTP Output Targets 2006:
At least 15 new varieties with resistance to late leaf spot and rust available and shared with partners

Farmer preferred varieties in India, Vietnam and China identified and disseminated amongst partners

Activity 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/PLK) 2009

Ninety-seven crosses (42 for foliar diseases, 22 for medium-duration, 10 for short-duration, and 23 for confectionery traits) were made during the 2005/06 post-rainy and the 2006 rainy seasons to generate populations for selection for high yield, diseases resistance, desired crop duration, and confectionery traits in desirable agronomic backgrounds. New parents used in hybridization included high-yielding foliar diseases tolerant breeding lines (ICGV 04060, ICGV 04055, ICGV 04078, and ICGV 04093); germplasm lines (ICG 7340, ICG 6843, ICG 7621, and ICG 6330); high-yielding and medium-duration advanced breeding lines (ICGV 04112, ICGV 04124, ICGV 04149, ICGV 99159, and ICGV 95069); short-duration advanced breeding lines (ICGV 00308, ICGV 93392, ICGV 00290, and Nyanda); high-yielding, advanced breeding lines with confectionery traits, (ICGV 99083, ICGV 00350, ICGV 00451, and ICGV 00440), and germplasm lines (ICG 6767, ICG 6670, and ICG 1651).

SN Nigam and R Aruna

Milestone: Evaluation of groundnut lines for resistance to late leaf spot (LLS) and rust during under field conditions:

Late leaf spot (LLS) (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*) are the most serious fungal diseases of groundnut, particularly in the rainy season. Systematic screening of groundnut germplasm and breeding lines was initiated in the field and laboratory to incorporate resistance into high yielding cultivars with agronomic and quality characters suited to different environments. Ten groundnut breeding lines (ICGV 37, ICGV 00005, ICGV 00064, ICGV 01270, ICGV 01276, ICGV 92267, ICGV 86590, ICGV 87846, ICGV 99029, and ICGV 00068) along with the susceptible cultivar TMV 2, and a resistant control ICG 13919, were evaluated against late leaf spot and rust at 61, 74, 92, 106, and 123 days after sowing (DAS) at ICRISAT, Patancheru, India, during the 2006 rainy season. Highly significant differences were observed among the genotypes in both the trials for disease score (LLS and rust) and leaf area damage (LAD).

Late leaf spot (LLS): At 92 days after sowing (DAS), of the ten advanced groundnut breeding lines evaluated, ICGV 00068 (LLS score = 2.7; LAD = 7.0) was highly resistant. Six lines showed a disease score between 3.0 – 5.0 and LAD = 11.0 - 26.0 as compared to the resistant check ICG 13919 (LLS score = 2.7 and LAD = 6.3) and susceptible check TMV 2 (LLS score = 7.0 and LAD = 60.0) (Fig. 1).

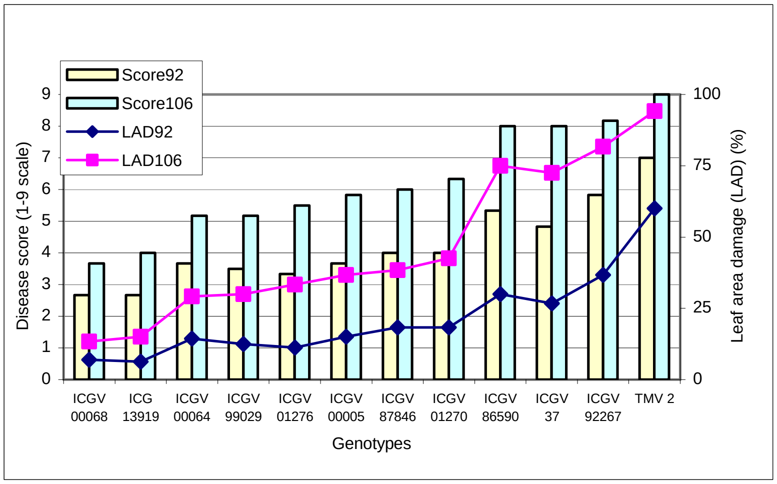

Fig. 1. Evaluation of advanced groundnut breeding lines for resistance to late leaf spot (ICRISAT, Patancheru, 2006 rainy season)

Rust: At 92 DAS, of the 10 advanced groundnut lines tested, eight lines showed a disease score of 1 – 2 and LAD = 0.3-1.7, and two lines (ICGV 92267 and ICGS 37) showed moderate levels of resistance (rust score = 3.8 -4.2, and LAD = 18.3 – 20.0) as compared to the resistant check ICGV 86699 (rust score = 1.8 and LAD = 0.8) and susceptible check TMV 2 (rust score = 6.0 and LAD = 40.0) (Fig. 2). ICGV 00064 showed resistance to both rust and LLS.

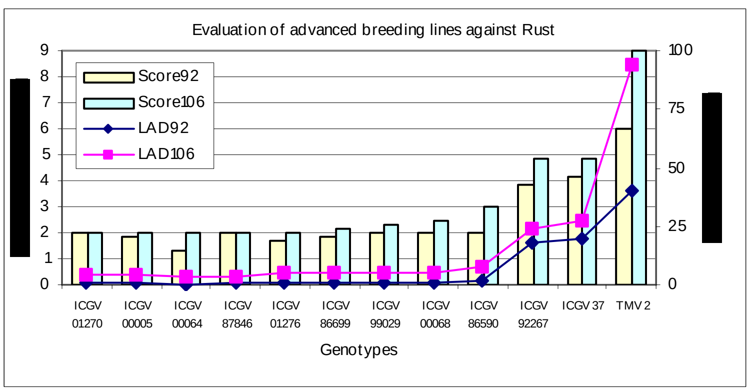

Fig. 2. Evaluation of advanced groundnut breeding lines for rust resistance (ICRISAT, Patancheru, 2006 rainy season).

Evaluation of advanced breeding lines for resistance to LLS and rust: Six replicated yield trials (elite foliar diseases resistant groundnut varietal trial (Spanish bunch) (EFDRGVT - SB), elite foliar diseases resistant groundnut varietal trial (Virginia bunch) (EFDRGVT - VB), advanced foliar diseases resistant groundnut varietal trial (Spanish bunch) (AFDRGVT - SB), advanced foliar diseases resistant groundnut varietal trial (Virginia bunch) (AFDRGVT - VB), preliminary foliar diseases resistant groundnut varietal trial (Spanish bunch) (PFDRGVT - SB), and preliminary foliar diseases resistant groundnut varietal trial (Virginia bunch) (PFDRGVT -VB); consisting of 101 advance breeding lines were screened for resistance to rust and LLS in an experimental sick-plot containing inoculum bearing infector-rows. Experiment was laid out in a broad-bed-and-furrow (BBF) system with two replications. Size of each plot was 1.5 x 4 m, with inter-row spacing of 30 cm, and plant to plant spacing of 10 cm within a row. Chemical sprays were used to control insect pests. At 45 days after sowing, plots were inoculated by spraying the infected and test rows with mixed conidial suspension of *P. personata* and *P. arachidis* urediniospores. After inoculation, perfo-irrigation was provided daily for 30 min in the evening for 30 days to increase humidity required for disease development. Diseases (LLS and rust) were scored on a 1 - 9 rating scale (1 = highly resistant, and 9 = highly susceptible) at 89 and 105 days after sowing.

Development of LLS and rust was uniform throughout the infector rows, and 100% infection was observed in the susceptible controls. Highly significant differences were observed among the genotypes in all the trials against LLS and rust. For all the trials, coefficient of variation was in the range of 4 to 22% for LLS, and 5 to 15% for rust . Of 101 breeding lines tested, none of the test lines was resistant to LLS. Twenty-four lines showed an overall disease severity score of 4.0. Another 16 lines had a score of 4.5, 29 lines were scored 5.0, and 15 lines rated as moderately resistant (score 5.5) (Table 1). Eighty-eight of these lines showed good resistance to rust (disease score of 2); 11 lines scored 2.5 to 3; and the remaining two lines ICGV 05092 recorded 8.0 and ICGV 06160 scored as 6.5 at 105 days after sowing (Table 1).

Table 1: Evaluation of advanced breeding lines for late leaf spot and rust resistance (ICRISAT, Patancheru, 2006 rainy season)

Trial	**No. of lines tested**	**Disease severity rating**					
		LLS			**Rust**		
		1-3*	**4-6***	**7-9***	**1-3***	**4-6***	**7-9***
EFDRGVT (SB)	11	Nil	10	1	11	Nil	Nil
EFDRGVT (VB)	5	Nil	5	Nil	5	Nil	Nil
AFDRGVT (SB)	15	Nil	14	1	14	Nil	1
AFDRGVT (VB)	16	Nil	16	Nil	16	Nil	Nil
PFDRGVT (SB)	28	Nil	24	4	27	Nil	1
PFDRGVT (VB)	26	Nil	25	1	26	Nil	Nil
Total	**101**	**Nil**	**94**	**7**	**99**	**Nil**	**2**

*Disease score on a 1 - 9 scale, where 1 = highly resistant, and 9 = highly susceptible for LLS and rust.

Preliminary evaluation for resistance to foliar diseases: Two foliar disease-resistant groundnut variety (PFDRG - VT) trials consisting of 164 lines were screened against LLS and rust. Six lines showed resistance to LLS with a score of 3.0, while 121 had a score of 4 - 6. For rust, 137 lines showed high levels of resistance (disease score 2.0). The remaining lines had a score of >3.0 on a 1 - 9 scale.

Farid Waliyar, Lava Kumar, SN Nigam and R Aruna

Performance of F_2 to F_6 populations for resistance to LLS and rust under field conditions: Five breeding populations (F_2 to F_6, 118 lines) were evaluated for resistance to LLS and rust under field conditions during the 2006 rainy season in an un-replicated, 9 m row plot, with 60 cm inter-row spacing, and 10 cm distance between the plants. TMV 2, a highly susceptible cultivar to both LLS and rust, was sown in infector rows after every five test rows. Forty-five days after sowing, plots were inoculated by spraying 30 L of mixed suspension of *P. personata* conidia and *P. arachidis* urediniospores. One day after inoculation, perfo-irrigation was provided daily for 30 minutes in the evening up to 30 days to favor disease development. All the populations were evaluated on a 1 - 9 rating scale for reaction to foliar disease at harvest. The development of LLS was uniform throughout the infector rows. The breeding populations were categorized as resistant (disease score 1 - 3), moderately resistant (disease score 4 - 6) and susceptible (disease score 7 - 9). A few single plants from F_6 population showed moderate levels of resistance to LLS.

Farid Waliyar, Lava Kumar, SN Nigam and R Aruna

Screening of advanced breeding lines for resistance to *Aspergillus flavus* infection and aflatoxin contamination: During the 2005 post-rainy season, 106 advanced breeding lines were evaluated for resistance to *Aspergillus flavus* seed infection and aflatoxin contamination. The breeding lines were planted in five separate trials in the *A. flavus* sick plot. The fungal inoculum multiplied on sorghum and maize grains was applied in the soil at two-weekly intervals during the crop growth period, and end of season drought stress was imposed 30 days before harvest to facilitate seed infection. Harvesting was done manually and pods were sun dried for 2 - 3 days. Pods from each plot were collected separately, shelled manually and kernel sub-samples were analyzed for *A. flavus* seed infection by blotter plate method and aflatoxin contamination by indirect competitive ELISA. The seed infection in the test lines ranged from 0 to 40% and aflatoxin contamination was between 0 to 6,668 μg kg^{-1}, respectively. Five of the 30 elite aflatoxin-resistant lines (ICGV 01002, ICGV 01149, ICGV 02148, ICGV 02189, and ICGV 02191) showed <1% *A. flavus* seed infection and <2 μg kg^{-1} aflatoxin. All the 18 advanced Virginia bunch lines were susceptible (aflatoxin >20 μg kg^{-1}) to aflatoxin contamination. Among 21 advanced Spanish bunch varieties, eight lines (ICGV 03300, ICGV 03308, ICGV 03328, ICGV 03331, ICGV 03332, ICGV 03337, ICGV 03344, ICGV 03346, and ICGV 03352) had less than 5% seed infection and less than 5 g kg^{-1} aflatoxin. One hundred thirty advanced breeding lines in four replications were screened in the sick plot for resistance to *A. flavus* infection and aflatoxins contamination during the 2006 rainy season. Kernels were harvested, sun dried, and pods were stripped manually. The samples are being analyzed for *A. flavus* infection and aflatoxin contamination.

Farid Waliyar, SN Nigam and R Aruna

Milestone: Screening groundnut germplasm and breeding material for resistance to foliar pests organized (GVRR/SNN/HDU/RA) 2009

Consolidation of information on resistant sources for various insect pests on groundnut has been completed. Screening of elite breeding material against insect vectors and defoliators under field condition is in progress during the post-rainy 2006-07.

Milestone: 15 - 20 new high yielding lines with resistance to biotic stresses and quality, and adaptation traits identified and made available to NARS (SNN/RA/FW/PLK) - Annual

The trait-specific international trials are made available on request to collaborators in NARS. The promising lines from on-station elite trials feed into international trials, are organized every two years.

Foliar diseases resistance: We evaluated 369 advanced breeding lines (including controls) in 14 replicated trials, and 108 advanced breeding lines in 2 augmented trials during the 2005/06 post-rainy and the 2006 rainy seasons. The disease scores were recorded on a 1 - 9 scale (where 1 = no disease, and 9 = >80% foliage damaged) at 105 DAS.

In the elite variety trial, Spanish types, ICGV 02410 was the best performer (4.7 t ha^{-1} pod yield; 63% shelling outturn) during the 2005 rainy season. The highest yielding control in the trial was ICGV 98374 (4.2 ± 0.33 t ha^{-1}). ICGV 02410 performed equally well during the 2005 rainy season (3.4 ± 0.21 t ha^{-1} pod yield). In the elite variety trial, Virginia types, ICGV 02434 (4.9 ± 0.46 t ha^{-1} pod yield) outperformed the best control ICGV 98373 (3.2 ± 0.45 t ha^{-1} pod yield**).**

In Spanish elite variety trial, nine lines significantly out yielded (3.0 - 2.0 ± 0.21 t pod yield ha^{-1}) the highest yielding control, ICGV 98374 (1.6 t ha^{-1} pod yield). In this trial, ICGV 04060 (3.0 t pod yield ha^{-1}, 64% shelling out-turn, LLS score = 5.0, and rust score = 2.0) was the best line. In the Virginia elite variety trial, three entries ICGV 04087, ICGV 04091, and ICGV 04094 out-yielded the best control ICGV 86699 (1.7 t ha^{-1}, 60%, 4.0 and 2.0). Five lines (ICGV 02410 and ICGV 02411 in the Spanish group, ICGV 02429, ICGV 02434, and ICGV 02446 in the Virginia group) were selected for inclusion in international trials.

High oil content: Forty-six breeding lines were evaluated during the 2005/2006 post-rainy season for oil content and pod yield in a replicated trial. ICGV 01274 (5.5 t ha^{-1} pod yield, 49.0% oil content, and 1.9 t ha^{-1} oil yield) and ICGV 00009 (5.4 t ha^{-1}, 50.5%, 1.8 t ha^{-1}), produced significantly higher pod yield than the highest yielding control, ICGV 86564 (4.6 t ha^{-1}, 47.0%, 1.5 t ha^{-1}). Both of these lines also had higher oil yield. But for oil content *per se*, ICGV 00351 (4.3 t ha^{-1}, 51.0 %, 1.6 t ha^{-1}) and ICGV 00171 (4.4 t ha^{-1}, 51.5%, 1.5 t ha^{-1}) were quite good. The oil content of entries in this trial ranged from 51.5 - 44.7%, and the protein content from 26.9% - 18.4%. Twelve lines had an oil content ≥50%. In the 2006 rainy season, ICGV 01274 (4.3 t ha^{-1} pod yield) was the top performer under irrigated conditions.

Medium-duration: Seven hundred and ninety advanced breeding lines (including controls) in 16 replicated trials, and 76 lines in 2 augmented trials were evaluated in the 2005/2006 post-rainy and 2006 rainy seasons for pod yield and other agronomic traits.

In the advanced Spanish type trial in 2005/06, 12 lines significantly out-yielded (pod yield 4.6 - 5.6 ± 0.52 t ha^{-1}) the best control ICGS 11 (4.0 t ha^{-1} pod yield). The best entry in the trial was ICGV 04115 (5.6 t ha^{-1}pod yield, 68% shelling outturn, and 50.4% oil), followed by ICGV 04124 (5.5 t ha^{-1}, 69%, and 47.6%). In the advanced Virginia type trial 14 entries produced significantly higher pod yield (4.3 - 5.5 ± 0.60 t ha^{-1}) than the best control ICGS 76 (3.7 t ha^{-1}). ICGV 04140 (5.5 t ha^{-1} pod yield) and ICGV 04139 (5.5 t ha^{-1}) were the best entries in this trial. However, the former had higher 100-seed weight, and the latter higher oil content.

In the Spanish elite variety trial, all 7 test lines outperformed (3.7 - 4.8 ± 0.18 t ha^{-1} pod yield) the highest yielding control ICGV 95058 (2.5 t ha^{-1} pod yield) during the 2006 rainy season. The best entry ICGV 04124 (4.8 t ha^{-1}) originated from the cross (ICGV 92069 x ICGV 93184) x ICGV 98105. In the Virginia elite variety trial, three lines; ICGV 04149 (4.9 t ha^{-1}), ICGV 04140 (4.6 t ha^{-1}), and ICGV 04139 (4.6 t ha^{-1}), out-yielded the control, ICGV 86325 (2.7 ± 0.43 t ha^{-1}). The best entry came from (ICGV 92069 x ICGV 93184) x ICGV 99171 cross. In another Virginia elite variety trial (conducted with the material transferred from short-duration trials), all 22 lines significantly out-yielded (3.8-3.1 ± 0.43 t ha^{-1}) the best control ICGS 76 (2.5 t ha^{-1}). Seven medium-duration lines were selected in the 2005/2006 post-rainy season for inclusion in international trials.

Confectionery types: One hundred and sixty-two advanced breeding lines (including controls) were evaluated in nine replicated yield trials under high input conditions during the 2005/2006 post-rainy and the 2006 rainy seasons. In the 2005/06 post-rainy season, none of the test entries out-yielded the best control in any trial. In the 2006 rainy season, 6 lines (3.5 - 2.7 ± 0.16 t ha^{-1} pod yield; 57 - 66% shelling outturn; and 48 - 56 g 100-seed weight) out-yielded the best control ICGV 99085 (2.3 t ha^{-1}; 65% shelling out-turn; and 42 g 100 seed weight). The best entry ICGV 05176 (3.5 t ha^{-1}; 57% shelling outturn; 49 g 100 seed weight) came from ((ICGV 88414 x USA 63) x ICGV 95172) x ICGV 00440) cross. In another advanced trial (Virginia), 2 lines, ICGV 05198 (3.1 t ha^{-1}) and ICGV 05200 (3.1 t ha^{-1}) outperformed the highest yielding control ICGV 00440 (2.6t ha^{-1}). The best entry came from ((BPI Pn 9 x ICGV 95172) x ICGV 88414) x (USA 63 x ICGV 95172)).

Short-duration: We evaluated 385 lines (including controls) in 14 replicated trials and 192 advanced breeding lines in 4 augmented trials for their yield and other agronomic traits under irrigated conditions in the 2005 rainy and the 2005/2006 post-rainy seasons. The Spanish trials were harvested when the crop accumulated 1470 °Cd (equivalent to 90 DAS in the rainy season) and the Virginia and large-seeded trials when the crop accumulated 1705 °Cd (equivalent to 105 DAS in the rainy season) at ICRISAT Center, Patancheru, India.

None of the new breeding lines out-yielded the best control in all the eight replicated yield trials in 2005/2006 post-rainy season. In another trial, 45 elite entries, originating from different series of international short-duration groundnut varietal trial (ISGVT) in the past 10 years, and other elite trials, were evaluated with 4 controls in a 7 x 7 lattice design. Thirteen entries out-yielded (3.4-3.9 ± 0.36 t ha^{-1} pod yield) the highest yielding early-maturing control J 11 (3.0 t ha^{-1} pod yield). ICGV 00308 (3.9 t ha^{-1} pod yield), ICGV 97243 (3.8 t ha^{-1}), and ICGV 00338 (3.7 t ha^{-1}) were the most promising. ICGV 97243 belonged to the IX series, and ICGV 00308 to the X series of ISGVT and ICGV 00338 to elite trial.

In the Spanish elite varietal trial, 6 lines significantly out-yielded (1.8 - 1.4 ± 0.12 t ha^{-1} pod yield) the highest yielding control, Chico (1.1 t ha^{-1} pod yield) in 2006 rainy season. ICGV 03211 (1.8 t ha^{-1}), the best entry among the 6 lines, came from (ICGV 98191 x ICGV 93382) cross. In another Spanish elite varietal trial, 6 lines (2.4 - 2.0 ± 0.13 t ha^{-1} pod yield) produced significantly higher pod yield than the highest yielding control ICGV 91114 (1.8 t ha^{-1}). ICGV 02038 (2.4 t ha^{-1}), the best entry among the 6 lines, came from (ICGV 95244 x ICGV 92206) cross. Two lines (ICGV 02022 and ICGV 02144) were identified for inclusion in the international trials during the 2005/2006 post-rainy season.

SN Nigam and R Aruna

On station evaluation of groundnut genotypes for LLS: Ten advanced breeding lines were supplied to scientists at the University of Agriculture Sciences, Bangalore, Karnataka, India. These lines were planted during the 2005 rainy season at UAS, Hebbal Campus, Bangalore, along with the susceptible check TMV 2 to evaluate their resistance against LLS. The test genotypes were evaluated for disease severity at 15 day intervals and the final scores are presented in the Table 2. Six genotypes (ICGV 01270, ICGV 00005, ICGV 00064, ICGV 01276, ICGV 87846, and ICGV 00068) showed good level of resistance. All the ten genotypes are being evaluated during the 2006 rainy season to select promising lines for multilocation on-farm evaluation in southern Karnataka during the 2007 rainy season.

Table 2. On station evaluation of groundnut genotypes for LLS (UAS, Bangalore, 2005 rainy season).

Genotype	Percent disease index (PDI) as on 2/10/2005	Percent disease index (PDI) as on 15/10/2005	Percent disease index (PDI) as on 26/10/2005
ICGV 01270	16.66	23.33	32.21
ICGV 92267	46.66	79.99	94.99
ICGV 00005	15.55	21.10	33.33
ICGV 00064	15.55	26.66	33.88
ICGV 01276	14.99	23.33	31.66
ICGV 86590	44.44	72.21	78.32
ICGV 87846	19.99	28.33	39.44
ICGV 37	38.32	74.43	92.76
ICGV 99029	14.99	19.99	34.44
ICGV 00068	13.88	17.22	27.77
TMV 2	61.66	87.76	96.10

Farid Waliyar, Lava Kumar, SN Nigam and R Aruna

On-farm evaluation of *Aspergillus flavus* and aflatoxin resistant varieties in Andhra Pradesh, India: On-farm participatory varietal selection trials and the participatory evaluations of improved varieties have been carried out with four (ICGV 91278, ICGV 91328, ICGV 94379, and ICGV 94434) varieties in Anantapur; and five (ICGV 91114, ICGV 91341, ICGV 93305, ICGV 94379, and ICGV 94434) varieties in Pileru area, in Andhra Pradesh, India. The trials were planted in 18 farmers' fields in six villages of the each of the two districts. Performance of the 4 selected groundnut improved varieties was better in all the 18 farmers' fields in six villages in Anantapur district and produced higher pod and haulm yield than the control TMV 2. Highest pod yield 1029 kg ha^{-1} was obtained with ICGV 94434 in Cherlopalli village. The variety ICGV 94434 produced 40 - 43% higher pod yield in three villages, and in the remaining 3 villages it produced 23 - 34% higher pod yield than the control TMV 2. From each plot, about one kg pod sample was drawn (after recording the bulk pod yield). The damaged pod sub-samples and the remaining pods were shelled and sorted in large and small kernel sub-samples. Large seeds, which are mostly used for confectionery purpose, showed 0.4 - 32% *A. flavus* infection and 0 -897 µg kg^{-1} aflatoxin across the villages and varieties. Overall, improved varieties showed reduction in *A. flavus* infection (31 - 50%) and aflatoxin contamination (56 - 93%) over the controls. Aflatoxin levels in three varieties (ICGV 91328, ICGV 94379, and ICGV 94434) was <20 µg kg^{-1} against 128 µg kg^{-1} in control TMV 2. Analysis of immature small sized kernels showed *A. flavus* infection and aflatoxin contamination in the range of 0 - 22% and 0 - 679 µg kg^{-1} g, respectively. Three improved varieties showed 82 - 93% reduction (<10 µg kg^{-1}) in aflatoxin against 58 µg kg^{-1} in control, and these three varieties were promising in large seed category also. Irrespective of variety, kernels from damaged pods contained high levels of aflatoxin (range 88 - 393 µg kg^{-1}) because damaged pods are vulnerable to fungal infection and subsequent aflatoxin production. Considering the complex nature of the aflatoxins problem in groundnut, the overall mean of the six villages for large and small sized kernels of improved varieties showed good tolerance to aflatoxins contamination. In addition, these lines produced 15 - 34% higher pod and haulm yields than the local control TMV 2.

Farid Waliyar, Lava Kumar and SN Nigam

Milestone: Wild Arachis species evaluated for Tobacco streak virus (TSV) resistance and durable resistant genotypes identified (PLK/FW/SNN/RA) 2007

Evaluation of wild *Arachis* for resistance to *Tobacco streak virus*: Stem necrosis disease caused by *Tobacco streak virus* (TSV) has emerged as a potential threat to groundnut in southern states of India. All the 189 groundnut cultivars currently grown in India and over 400 cultivated genotypes tested at ICRISAT, Patancheru, India are highly susceptible to the virus. Therefore, wild relatives of peanut were evaluated to identify potential sources of resistance to TSV infection. Fifty-six germplasm accessions from twenty wild *Arachis* species of four sections (*Arachis, Erectoides, Procumbente,* and *Rhizomatosae*) along with the susceptible peanut cultivars (JL 24 and K 1375) were evaluated for resistance to TSV under greenhouse conditions by mechanical sap inoculations. Percent

TSV infection was recorded both on inoculated and subsequently emerged leaflets based on visual symptoms and by enzyme-linked immunosorbent assay (ELISA). Systemic virus infection in the test accessions ranged between 0 and 100%. Twenty-four of these accessions in section *Arachis* that had 0 to 35% systemically infected plants were re-tested, and eight of these accessions did not show systemic infection in repeated trials in the greenhouse. These were ICG 8139, ICG 8195, ICG 8200, ICG 8203, ICG 8205, and ICG 11550 (*A. duranensis*), ICG 8144 (*A. villosa*), and ICG 13210 (*A. stenosperma*). Although, these accessions showed TSV infection in inoculated leaves ranging between 0 and 100%, the virus was not detected in the subsequently emerged leaves, indicating block in systemic spread of virus amounting to the disease resistance. The eight TSV resistant accessions are cross compatible with *A. hypogaea* for utilization in breeding for stem necrosis disease resistance. The resistant accessions, ICG 8139 and ICG 11550 also possess high levels of resistance to rust (*P. arachidis*) and late leaf spot (*P. personata*), and ICG 8144 to Peanut bud necrosis virus, and thus have multiple resistance to virus and pathogens, and can be used to develop multiple disease resistant peanut varieties through inter-specific breeding.

Lava Kumar, Farid Waliyar, SN Nigam and R Aruna

Milestone: 50 lines of advanced generation interspecific derivatives of groundnut evaluated for LLS disease and promising lines identified (FW/NM/PLK) 2008

Screening of advanced interspecific derivatives against late leaf spot resistance: About 84 selections from 4 wide crosses (Arachis kempf-mercadoi, A. glabrata, A. batizocoi, and A. duranensis) were screened for resistance to late leaf spot (LLS) under field conditions during 2006 rainy season. Field trials were laid out in a broad-bed-and-furrow (BBF) system with three replications. The size of each plot was 1.5 x 4 m, with inter-row spacing of 30 cm, and plant to plant spacing of 10 cm. TMV 2, a highly susceptible cultivar to LLS was used as an infector row after every five-test rows. Chemical sprays were used to control insect pests. At 45 days after sowing, plots were inoculated by spraying the conidial suspension of P. personata urediniospores. After inoculation, perfo-irrigation was provided daily for 30 min in the evening for 30 days to create high humidity required for disease development. The LLS incidence and severity was scored on a 1 - 9 rating scale at 91 and 106 days after sowing. The development of LLS was uniform throughout the infector rows. Among the test lines, highly significant differences were observed and coefficient of variation was in the range of 14.4 to 15.1%. Out of 84 interspecific derivatives, twenty-two lines from A. hypogaea X A. cardenasii showed high level of resistance to LLS with a score of 2, Fifty-one lines had a score of 2 to 3, nine had a score of 3 to 4, and the remaining two lines were rated >5 at 106 days after sowing (Fig. 3). The disease severity in the susceptible check was 9.0. Promising lines with a disease rating of 3 and less will be advanced.

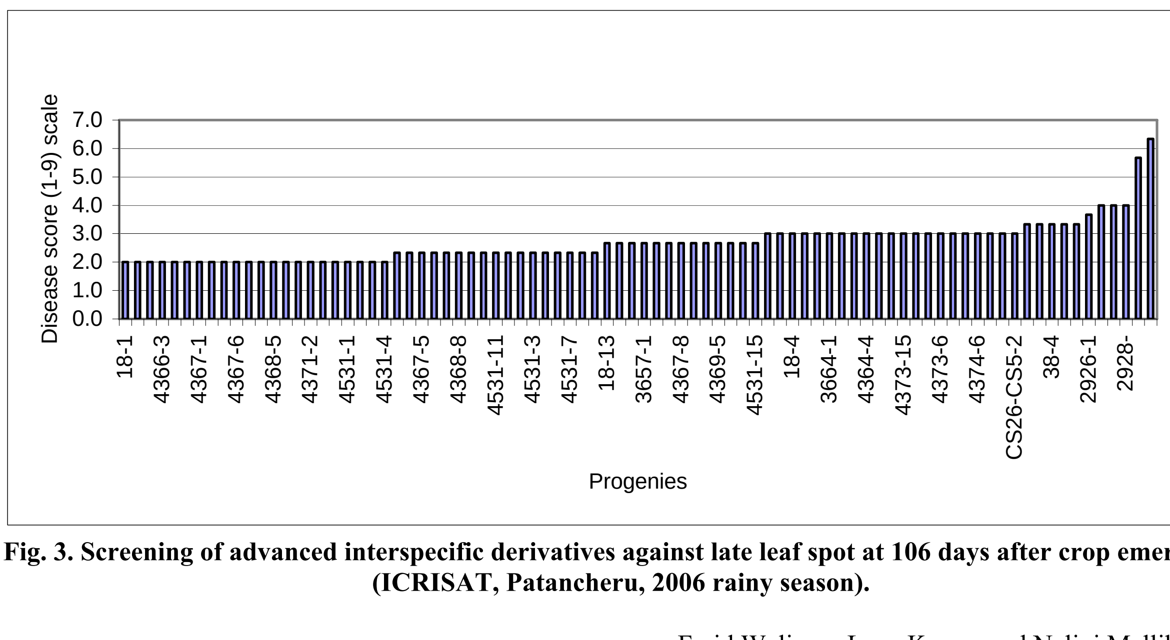

Fig. 3. Screening of advanced interspecific derivatives against late leaf spot at 106 days after crop emergence (ICRISAT, Patancheru, 2006 rainy season).

Farid Waliyar, Lava Kumar and Nalini Mallikarjuna

Evaluation of progenies from crosses of wild *Arachis* for resistance to *Aspergillus flavus*: Sixty progenies from wide hybridization crosses were evaluated for resistance to *A. flavus* seed colonization by *in vitro* assay. From each progeny, 60 seeds were surface sterilized with sodium hypochlorite and inoculated with *A. flavus* spores and kept in a moist blotter paper in a petridish in a humid box and incubated at 28°C for 6 days. Percent seed infection at the end of the 6^{th} day was estimated. The seed colonization ranged between 7 to 52% in all the progenies evaluated. Only 5 progenies (numbers. 2929-6, 2929-15, 4367-3, 4368-7, and 4373-15) showed less than 10% seed infection, while the rest showed a susceptible reaction. Uninfected seed from all the sixty progenies were retrieved and planted in the *A. flavus* sick plot at ICRISAT-Patancheru, for resistance evaluation under field conditions during the 2006 rainy season. Field screened samples are being processed for *A. flavus* seed infection and aflatoxin contamination and results are awaited.

Farid Waliyar, Lava Kumar and Nalini Mallikarjuna

Evaluation of interspecific derivatives for resistance to LLS: Eighty-four advanced interspecific derivatives lines were screened for LLS in 2005, which had a score of 2 to 3 on a 1 - 9 scale (1 = immune, and 9 = highly susceptible). These were screened for late leaf spot (LLS) in rainy season 2006. The lines which had a score of less than 3 in 2006, are presented in Table 3.

Table 3. Groundnut interspecific derivatives with stable resistance to LLS (ICRISAT, Patancheru, 2006 rainy season).

Genotype No:	Generation	*Wild species used in the cross*	2005	2006
LCBG-1	BC2F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-2	BC5F6	*A .hypogaea* x *A. cardenasii*	2	2.0
LCBG-3	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-4	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-5	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-6	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-7	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-8	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-9	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-10	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-11	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-12	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBG-13	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-14	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-15	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-16	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-17	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBG-18	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBP-19	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBP-20	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-21	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBG-22	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-23	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBG-24	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-25	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.7
LCBG-26	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-27	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-28	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-29	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBG-30	BC3F5	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBG-31	BC3F5	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-32	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.0
LCBG-33	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0

Genotype No:	Generation	*Wild species used in the cross*	2005	2006
LCBG-34	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-35	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-36	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-37	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.7
LCBG-38	BC5F6	*A. hypogaea* x A. cardenasii	3	2.0
LCBG-39	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBG-40	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.0
LCBP-41	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3
LCBP-42	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBP-43	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBP-44	BC5F6	*A. hypogaea* x *A. cardenasii*	3	2.3
LCBP-45	BC5F6	*A. hypogaea* x *A. cardenasii*	2	2.3

Farid Waliyar, Nalini Mallikarjuna and Lava Kumar

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/PLK) 2009

With the aim of selecting farmer-preferred varieties under moisture stress and popularize them, an Integrated Scheme of Oilseeds, Pulses, Oilpalm and Maize (ISOPOM)-funded 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 Andhra Pradesh, Orissa, and Gujarat. Anantapur and Chittoor districts were selected for project implementation in Andhra Pradesh. A farmer participatory varietal selection (FPVS) trial consisting of 9 varieties (K 1271, K 1375, TCGS 888, TPT 25, ICGV 00350, ICGV 00308, ICGV 86015, ICGV 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 Andhra Pradesh . Results of the FPVS Mother-baby trials would be available in the near future.

SN Nigam and R Aruna

<u>Progress reported towards the achievement of milestone for 2007 above will contribute towards achievement of the milestones listed below.</u>

Milestone: Five interspecific derivatives of groundnut evaluated for TSV and peanut bud necrosis virus (PBNV) diseases and promising lines identified (NM/FW/PLK/SNN/RA) 2010

Milestone: Field trials of five stable, promising interspecific derivatives conducted in target location for LLS resistance and yield (NM/FW/PLK/SNN/RA) 2011

Milestone: Field trials of three stable and promising derivatives for TSV and peanut bud necrosis diseases conducted in Anantapur and other target locations (NM/FW/PLK/SNN/RA) 2012

Activity 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 rust and 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 the inheritance of components of LLS resistance. Under controlled environmental conditions, fully expanded quadrifoliate leaves of 45 days old plants (third or fourth from the top) of each line were excised and planted in sand cultures (roughly 1.5 cm thick) in plastic trays (39.5 × 29 × 7 cm). In each tray, 20 leaflets were planted and the trays were covered with plastic bags and incubated in the growth chamber at 24 ºC and 85% relative humidity. The LLS inoculum (30000 spores ml^{-1}) was sprayed on both the surfaces of each leaflet. Some plants showed latent period (LP) of 30 - 36 days after inoculation and 2 - 5 lesions with minimum lesion diameter (<0.5 mm). Detailed observations on incubation period, latent period, lesion number, % leaf area damage (LAD), and lesion diameter were recorded. In the field, plants were inoculated with conidial suspension of *P. personata* at 50 DAS. After inoculation, perfo-irrigation was provided daily for 15 min in the evening for 30 days. The field observations included % defoliation at 75, 90, and 105 DAS, and the disease scores on a 1- 9 scale. The data are being processed.

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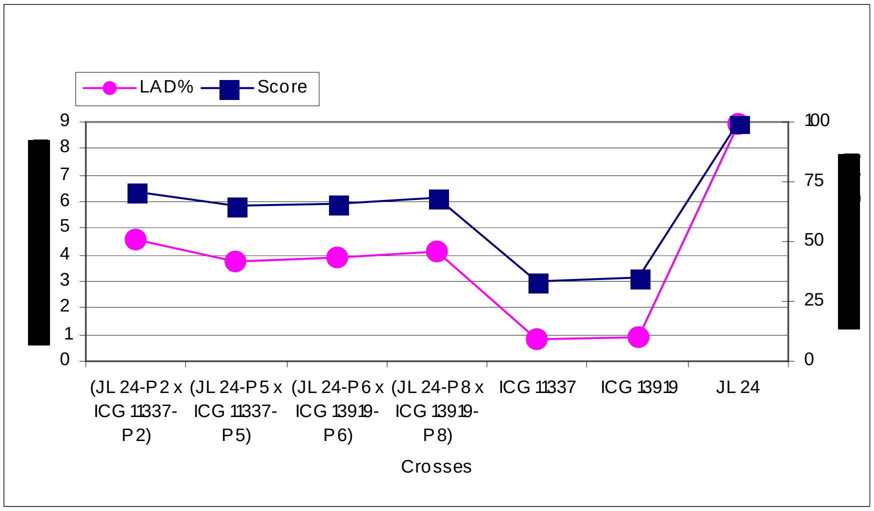
Inheritance of resistance to late leaf spot (LLS) under field and controlled environment conditions: F_3 progenies (439) of two crosses (ICGV 11337 X JL 24 and ICGV 13919 X JL 24) along with parental lines (total 2556 single plants) were planted in an unreplicated trial in 60 cm inter-row spacing, and 10 cm between the plants, and screened for resistance to LLS under field conditions during the 2006 rainy season. TMV 2, a highly susceptible cultivar, was used as an infector row after every five-test rows. Plants in field trials were inoculated with conidial suspension of *P. personata* at 45 days after sowing. After inoculation, perfo-irrigation was provided daily for 30 min in the evening hours for 30 days. Subsequently, leaf area damage (%) and percentage of defoliation was measured in each plant. Plant reaction to LLS was recorded on a 1 - 9 rating scale at 82, 97, and 110 days after sowing (DAS). Of the two crosses and three parents, only two plants from JL 24-P6 x ICG 13919-P6, and one plant from JL 24-P2 x ICG 11337-P2 showed high levels of resistance to LLS with a score of 2.0; 42 progenies had a score of 3.0, 218 had a score of 4.0, and 337 recorded a score of 5.0 at 110 days after sowing. Remaining plants were scored >6.0. Data showed that the segregation is very high in the crosses, and there were no differences in the parent line plants (Table 4).

Table 4. Area under the disease progress curve (AUDPC), disease score, and leaf area damage (LAD) in F_3 progenies (ICRISAT, Patancheru, 2006 rainy season).

Crosses	No of Progenies	AUDPC			Score *			LAD (%) *		
		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	1	752	647	935	3	3	3	9	6	10
ICG 13919	1	719	593	813	3	3	4	10	6	12
JL 24	1	1779	1553	1987	9	9	9	100	95	100

* Score = Late leaf spot disease score on 1 - 9 scale; LAD = Leaf area damage (%) at 110 days after sowing.

Based on mean data of all the plants in each progeny, four progenies and two parent lines showed resistance to LLS with score of 3.0, 38 progenies showed a disease score of 4.0, 79 had score of 5.0, and the remaining progenies recorded a score of 6 - 9 on 1 - 9 scale. Leaf area damage was 7.5 - 95.5%. Area under the disease progress curve (AUDPC) was observed in a range from 615 to 2285 among the progenies at 110 days after sowing. Taking the mean data of all the plants and progenies in each cross, it was observed that the AUDPC, disease score and leaf area damage were more than double in JL 24 and in crosses, compared to ICG 11337 and ICG 13919 parent lines (Fig. 4a, b).



Crosses are mixed – Needs clarity (Spread)

Fig. 4a. Disease score and leaf area damage at 110 days after sowing in F_3 crosses (mean of all progenies) (ICRISAT, Patancheru, 2006 rainy season).

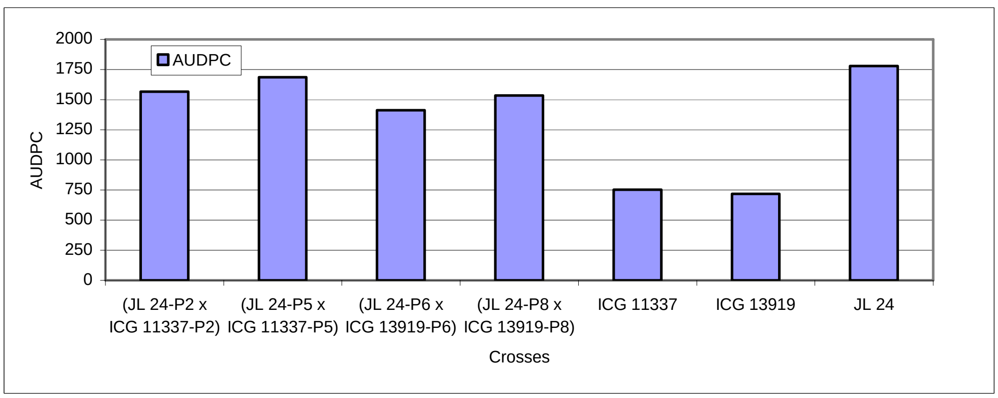


Fig. 4b. Area under the disease progress curve (AUDPC) of F_3 crosses (mean of all progenies of each cross) (ICRISAT, Patancheru, 2006 rainy season).

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Milestone: Knowledge of inheritance of traits associated with drought tolerance in three crosses gained and appropriate breeding strategy devised (SNN/RA/VV) 2009

To study the inheritance of traits associated with drought tolerance, four crosses (ICGS 76 x ICGV 93291, ICGV 99029 x ICGV 91284, JL 24 x ICGV 86031, and ICR (Is this ICR or ICG?) 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). The F_1 plants have been produced and backcrosses would be attempted in the 2006/2007 post-rainy season.

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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 blanching ability), parents, F_{1s}, F_{2s} and backcrosses of two crosses (Chico x ICGV 01393 and Chico x ICGV 02251) along with their reciprocals have been sown in a replicated trial during the 2006/2007 post-rainy season.

SN Nigam and R Aruna

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_4 stage. Two populations (ICGV 01393 x Chico and ICGV 02251 x Chico) for confectionery traits have also been developed and the material is in F_3 stage.

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Output target 6A.2: Promising transgenic events of groundnut for resistance to TSV and PBNV available for commercialization and introgression in locally adapted germplasm

Activity 6A.2.1: Develop transgenic events of groundnut for resistance to TSV and evaluate their performance under contained greenhouse and field conditions

Milestone: 100 transgenic events of groundnut with TSVcp gene developed and screened in contained greenhouse (KKS/PLK/SNN) 2007

Stem necrosis disease caused by the *Tobacco streak virus* (TSV) has emerged as a serious problem on groundnut in Andhra Pradesh, and Karnataka, India. All the currently grown groundnut varieties are susceptible to the virus. Research has been initiated to incorporate resistance to TSV in groundnut by using TSV coat protein (*TSVcp*) gene through *Agrobacterium tumefaciens*-mediated genetic transformation of popular groundnut cultivars JL 24, TMV 2, and ICGV 91114. Twenty events, with six plants per event, were planted in the P_2 greenhouse. A cotyledonous leaflet was collected from 8 - 10 day old plants and analyzed for transgene by PCR assay, which revealed *TSVcp* transgene in 68 of 118 plants tested (58% transformation rate).

At the 3-leaf plant growth stage (8 - 10 day old plants), all the 118 test plants [alongwith susceptible control (JL 24)] were inoculated by standard mechanical sap inoculation procedure using 1: 30 (w/v) TSV-affected French bean leaf sap extracts. All the inoculated plants developed necrotic symptoms on the inoculated leaves 7-days post inoculation and tested positive to TSV with ELISA. These plants were monitored at weekly intervals for systemic virus infection by testing newly emerged apical leaves by ELISA, and symptoms were recorded. All the non-transgenic plants (*TSVcp* gene negative in PCR assay) were susceptible to TSV and showed symptoms typical of TSV infection within 2-weeks post inoculation. Of the 68 transgenic plants (*TSVcp* gene positive), 24 plants (35.2%) showed negative reaction to TSV (no symptoms) or delayed expression of symptoms compared to controls. Delayed symptom expression (by 2 - 3 weeks compared to controls) was also observed in 42 plants (61.7%). After appearance of initial symptoms, disease progress was rapid leading to premature death of the plants. It is likely that these plants may have some tolerance at early growth stages offering resistance to virus spread, but this mechanism is not sufficient to protect plants at later stages. All the symptomatic plants, either transgenic or controls, tested positive to TSV with ELISA, and all asymptomatic plants were negative, indicating a correlation between virus presence and the stem necrosis disease.

Eight plants from six events (1B, 1F, 3E, 4B, and 9C) did not show any systemic symptoms and non-inoculated leaves were TSV negative, indicating putative TSV resistance in these plants. Considering the fact that TSV was detected in the inoculated leaves of these plants and the lack of virus in the subsequently emerged leaves suggests a blockage in the systemic spread of virus, which seems to be responsible for the virus resistance. Delayed symptom expression (at the time of flowering) was observed on one or two branches in events 9B, 19B, and 22B. These plants apparently had normal growth pattern. It is likely that these plants may also have some resistance amounting to the protection. Further evaluation of these events is being continued. Recently, genetic transformation of groundnut cv. ICGV 91114 has also been undertaken to incorporate transgenic resistance to TSV using *TSVcp* gene.

KK Sharma, Lava Kumar and Farid Waliyar

Progress reported towards the achievement of milestone for 2007 above will contribute towards achievement of the milestones listed below.

Milestone: At least 10 promising TSVcp transgenic events identified and the disease resistance characterized under contained green house conditions (KKS/PLK/SNN) 2008

Milestone: Five promising TSVcp transgenic events identified and the disease resistance characterized under contained field conditions (KKS/PLK/SNN) 2009

Milestone: Two best transgenic events with resistance to TSV used for introgression into locally adapted groundnut genotypes and their evaluation (KKS/PLK/SNN/RA) 2010

Milestone: Commercialization package for groundnut with transgenic resistance to TSV available for deployment (KKS/PLK/SNN/RA) 2011

Activity 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 PBNVnp gene or alternative gene developed and screened in contained greenhouse (KKS/PLK/SNN/RA) 2008

Peanut bud necrosis disease (PBND) 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 engineer 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. The progeny of the transgenic plants were mechanically inoculated with PBNV at two concentrations, 1: 50 and 1: 100 (w/v) under P_2 greenhouse conditions. In the T_1 generation, at 1: 100 concentration of leaf sap inoculum, 24 of the 36 events tested did not show any symptoms and virus was not detected in these plants with ELISA. However, at higher concentration [1: 50], all the 24 events were infected by the virus, but the symptoms were delayed by 40 to 60 days in six events, when compared with the untransformed controls, which showed nearly 100% mortality within two weeks after inoculation. The 24 events were evaluated in a contained on-station trial at ICRISAT, Patancheru farm, during 2005. Planting was done with wide spacing to attract thrips vector for the virus inoculation. Most of the 24 events were affected by PBND, however, 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 PBND 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 PBND. 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. Further studies have been planned to develop RNAi construct to counter the effect of NSs gene for transformation either by genetic engineering or conventional crossing into *PBNVnp* transgenic events. 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.

KK Sharma, Lava Kumar and Farid Waliyar

Progress reported towards the achievement of milestone for 2008 will contribute towards achievement of the milestones listed below.

Milestone: At least 10 promising transgenic events identified and resistance to PBNV characterized under contained greenhouse conditions (KKS/PLK/SNN/RA) 2009

Milestone: Five promising PBNVcp or alternative gene transgenic events identified and the disease resistance characterized under contained field conditions (KKS/PLK/SNN/RA) 2010

Milestone: Two best transgenic events with resistance to PBNV used for introgression into locally adapted groundnut genotypes and their evaluation (KKS/PLK/SNN/RA) 2011

<u>Chickpea</u>

Output A: Improved germplasm and varieties of sorghum, pearl millet, pigeonpea, chickpea, and groundnut with pro-poor traits and advanced knowledge of selection tools and breeding methods made available to partners internationally

MTP Output Target 2006: 20 new high yielding fusarium wilt resistant kabuli and desi chickpea breeding lines made available to NARS

Chickpea: Six lines (ICC 14194, ICC 14206, ICC 14215, ICC 17109, WR 315, and KAK 2) have been found to be asymptomatic to Fusarium wilt in chickpea. Three lines (ICCX-990026-F3-BP-25-BP, ICCX-990026-F3-BP-34-BP, and ICCX-990026-F3-BP-40-BP) were also superior to KAK 2 in seed yield, 100-seed weight, and flowering. Five lines (ICCV 05525, ICCV 05526, ICCV 05534, ICCV 97207, and ICCV 98501) have been identified to be resistant to BGM and FW, while ICCV 05523 showed resistance to AB and FW.

Large-seeded Kabuli chickpea germplasm lines ICC 14194 and ICC 14198 have been found to be very early (days to maturity <100 days) and had 50 to 53 g 100 seeds^{-1}, suggesting that it is possible to breed early-maturing Kabuli varieties with extra-large seed with FW resistance. Analysis of eight Indian isolates of Ascochyta using 20 RAPD primers (decamers) placed the isolates into two groups.

The 2-day-old eggs of *Helicoverpa armigera* can be stored at 10ºC for 10 days for bioassays at convenient times on insect host plant interactions, biological control, and toxicology. The genotypes RIL 27, RIL 51, RIL 81, RIL 83, ICC 10613, ICCL 87315, ICCL 87322, ICCL 87315, and ICCV 10 suffer less damage by *Helicoverpa* and have a yield potential comparable to commercial cultivars, and these can used in chickpea improvement for resistance to *H. armigera.*

High levels of antibiosis to *H. armigera* have been recorded in wild relatives of chickpea belonging to the tertiary gene pool (*Cicer judaicum*, *C. bijugum*, *C. cuneatum*, and *C. microphyllum*), and moderate levels of resistance in the secondary gene pool (*C. reticulatum*).

Bacillus thuringiensis (*Bt*) sprays on chickpea reduced the cocoon formation of *Campoletis chlorideae* reared on *Bt* intoxicated larvae of *H. armigera* (18.7 - 38.7% compared to 69.3 to 77.3% on untreated controls). The ELISA test indicated the presence of *Bt* protein in the *H. armigera* larvae fed on *Bt* treated chickpeas, while no *Bt* protein was detected in the cocoons and adults of the parasitoid, *C. chlorideae*, suggesting that lower survival of the parasitoid was due to the poor quality of the host.

Output target 6A.1: Nearly 50 - 100 chickpea breeding lines with high yield, improved seed quality traits, and resistance to one or more biotic stresses [Fusarium wilt (FW), Ascochyta blight (AB), Botrytis gray mold (BGM) and *Helicoverpa*] developed and disseminated to the NARS

Activity 6A.1.1: Develop chickpea breeding lines (Desi and Kabuli) with enhanced resistance to AB, BGM, and FW

Milestone: 15 - 20 high yielding FW resistant Desi and Kabuli chickpea breeding lines made available to NARS (SP/PMG) Annual

Evaluation of advanced Desi and Kabuli chickpea breeding lines and populations for resistance to Fusarium wilt: We evaluated 162 entries (143 + 19 checks), 244 crossing block entries/parents, 47 F_2 and three F_4 populations for FW resistance under artificial epiphytotic conditions. In addition, preliminary yield trial (PYT)-Desi (23 + 3), PYT-Kabuli (52 + 8), advanced yield trial (AYT)-desi (18 + 2), AYT-Kabuli (14 + 2), international chickpea screening nursery (ICSN)- Desi (18+2), and ICSN-Kabuli (18+2) were also evaluated for resistance to wilt. Wilt incidence in early-wilting cultivar, ICC 4951 was 100% in 30 days after sowing (DAS) and same in 90 DAS in the late wilting cultivar, K850 across the wilt-sick field. In the PYT-Desi, nine entries (ICCX 990009-F_3- BP-9-BP, ICCX 990009-F_3- BP-12-BP, ICCX 990022-F_3- BP-2-BP, ICCX 990009-F_3-BP-13-BP, ICCX 990009-F_3- BP-19-BP, ICCX 990009-F_3- BP-20-BP, ICCX 990011-F_3- BP-12-BP, ICCX 990026-F_3- BP-6-BP, and ICCX 970010-F_3-BP-P13-BP-BP) showed a resistant (<10% FWI incidence) reaction. In PYT-Kabuli, 17 were asymptomatic and 20 were resistant (<10% FW incidence). In AYT-Desi, ICCX 970047-BP-BP-P24-BP-BP-BP, and ICCX 970047-BP-BP-P52-BP-BP-BP were asymptomatic, and eight lines showed a resistant reaction. In AYT-Kabuli, four were (ICCX 980068-F_4-P10-BP-BP, ICCX 980068-F_4-P13-BP-BP, ICCX 980068-F_4-P23-BP-BP, and ICCX 970075-BP-

BPP43-BP-BP-BP) asymptomatic and three were resistant. In ICSN-Desi, ICCV 04103 and ICCV 05114 were asymptomatic and 11 lines were resistant to wilt. Among the ICSN-Kabuli entries, seven genotypes (ICCV 03407, ICCV 04305, ICCV 04308, ICCV 04309, ICCV 05306, ICCV 05308, and ICCV 05312) were free from wilt, and eight were resistant (10%). In 244 crossing block entries, six lines (ICC 14194, ICC 14206, ICC 14215, ICC 17109, WR 315, and KAK 2) were asymptomatic and 10 lines (Vijay, Jumbo 2, JG 11, JGK 1, ICCV 89302, ICCV 98502, ICC 7032, ICC 13053, ICC 14248, and ICC 16340) were resistant. Individual healthy plants were selected from F_2 and F_4 populations.

Suresh Pande and PM Gaur

International Chickpea Screening Nurseries (ICSNs) of Desi and Kabuli chickpea: A total of 61 sets of two ICSNs (ICSN-Desi and ICSN-Kabuli) were supplied to NARS in eight countries (Australia, Bangladesh, Ethiopia, India, Jordan, Myanmar, Nepal, and Pakistan) during 2005/06. Each nursery consisted of 18 entries and two checks - one common check (ICCC 37 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 4.0 m each. One set of each nursery was evaluated at ICRISAT-Patancheru. The results from India were compiled in a report, which was distributed to Indian NARS during the annual meeting of All India Coordinated Research Project on Chickpea at Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India. The most promising breeding lines were ICCV 03203, ICCV 05113, and ICCV 04111 in ICSN-Desi; and ICCV 04311, ICCV 05308, and ICCV 97306 in ICSN-Kabuli. During the 2006 cropping season, 67 sets of ICSN-Desi and ICSN-Kabuli were supplied to NARS in 9 countries (Brazil, China, India, Iraq, Myanmar, Nepal, Pakistan, Portugal, and South Africa). In addition to these, 812 samples of advanced breeding lines, 191 of released varieties, and 52 samples of segregating populations were supplied to 11 countries (Australia, Canada, England, Eritrea, India, Iraq, Japan, Mali, Morocco, Nigeria, and Vietnam).

PM Gaur

Evaluation of advanced breeding lines of Desi and Kabuli chickpeas: Advanced breeding lines of Desi (41 lines) and Kabuli (56 lines) chickpeas were evaluated in two advanced yield trials (AYTs) and four preliminary yield trials (PYTs) during the 2005/06 post rainy season. Three most promising lines identified in AYT-Kabuli included ICCX-980061-F4-P15-BP-BP, ICCX-980068-F4-P10-BP-BP, and ICCX-980068-F4-P13-BP-BP. These lines outperformed the best check, KAK 2 with respect to seed yield, 100-seed weight, and earliness, and had high level of FW resistance. In AYT-Desi, ICCX-980055-F4-P53-BP-BP and ICCX-970038-BP-BP-P12-BP-BP-BP were promising for yield, ICCX-970047-BP-BP-P24-BP-BP-BP and ICCX-970047-BP-BP-P52-BP-BP-BP for seed size and FW resistance, and ICCX-970077-BP-BP-P32-BP-2BP-BP for earliness and seed size. Three lines (ICCX-990026-F3-BP-25-BP, ICCX-990026-F3-BP-34-BP, and ICCX-990026-F3-BP-40-BP) were superior to KAK 2 in seed yield, 100-seed weight, and flowering. ICCX-990006-F3-BP-10-BP showed >12% seed yield increase over KAK 2. In the PYT-Desi, ICCX-990023-F3-BP-3-BP had more 100-seed weight, and higher level of FW resistance as compared to check variety ICCC 37.

PM Gaur and Suresh Pande

Milestone: 20 - 30 sources of resistance to FW, BGM, and AB tested for stability across locations and pathotypes in Asia (SP/PMG) Annual

Around 30 Fusarium wilt, Ascochyta blight, and Botrytis gray mold resistant/moderately resistant cultivars were evaluated at different locations and pathotypes to identify stable and broad-based resistance to these diseases.

Chickpea wilt and root rot nursery (CWRRN): Chickpea wilt and root rot nursery consisted of 30 entries (28 wilt resistant + 2 wilt susceptible cultivars) and was evaluated at 22 locations in India during 2005/06 season. Each entry was planted in one row, 4 m long, and there were two replications. Data on wilt was recorded at the flowering and at maturity stages of the crop. Data from fourteen locations (Akola, Badnapur, Bangalore, Berhampore, Dhaulakuan, Dholi, Hazaribagh, Hisar, ICRISAT, Patancheru, Jabalpur, Junagadh, Ludhiana, Rahuri, and Sehore) were received and compiled. Incidence of FW was very high in both susceptible cultivars at all the locations, except at Hazaribagh, where the nursery was planted in a normal field. ICC 12467 and ICC 14433 in eight locations, ICCX 950106-F4-66P-BP in seven locations, and ICC 14344, ICC 14391, ICC 14432, ICC 14436, and ICC ICCX 950110-F4-26P-BP-BP in five locations were found to be resistant (<10% incidence) to wilt. Preliminary results indicated considerable diversity in the population of *F. oxysporum f.sp. ciceris.*

International Ascochyta blight nursery (IABN): Thirty- nine AB promising entries and one susceptible check were included in IABN and evaluated under field conditions at two locations (Islamabad and Attok) in Pakistan, and five locations (Dhaulakuan, Gurdaspur, Ludhiana, Hisar, and Patancheru) in India. Each entry was planted in two replications with one row of 2 - 4 m long. Artificial inoculation with conidial suspension was done at flowering and pod initiation stages of the crop at all the locations. The IABN was evaluated under controlled environment conditions at ICRISAT following standardized evaluation technique. Data were received from all the five Indian locations, but not from Pakistan. Susceptible cultivar Pb 7 showed a susceptible reaction at all the five locations in India. Eight lines; ICC 1069, ICC 1400, ICC 12952, ICC 15978, ICC 1700, ICCX 810800, ICCX 900221-31-PABR, and ICCX 910028-46 PABR-BP-1PABR-L were showed resistant (1.1 to 3 rating on 1 - 9 rating scale) to moderately resistant (3.1 to 5 rating) reaction to AB at all the five locations in India. ICC 4991 and ICC 14344 were found to be susceptible at all the five locations.

International Botrytis gray mold nursery (IBGMN): The IBGMN consisted of 30 entries (29 moderately resistant and one susceptible check), and was evaluated under field conditions at two locations in Nepal (Rampur and Tarahara), two locations in Bangladesh (Ishrudi and Jessore), and four locations in India (Pantnagar, Gurdaspur, Ludhiana, and ICRISAT-Patancheru). At ICRISAT- Patancheru, the nursery was evaluated under controlled environment conditions. All the entries were artificially inoculated with conidial suspension of the local isolate at the flowering and pod initiation stages of the crop at all the locations, except at Tarahara, Nepal; where the nursery was evaluated under natural epiphytotic conditions. Data was received from Ludhiana, Pantnagar, and ICRISAT-Patancheru. Susceptible cultivar showed a highly susceptible reaction at all the three locations. ICC 1069 and ICCX 850498-3PN-17H-BH-BH in three locations; and ICC 12512, ICC 12952, ICC 14344, ICC 14559, ICC 14824, ICCV 89302, ICCV 89303, ICCV 98505, ICCL 86242, ICCL 87322, and ICCX 860029-BH-1PN-BPN-B in two locations (ICRISAT, Patancheru and Pantnagar) were found to be moderately resistant (3.1 to 5 rating on a 1 - 9 rating sale).

Suresh Pande and NARS Collaborators

Milestone: 5 - 10 new sources of resistance to AB and BGM identified (SP/PMG) 2009

Identification of new sources of resistance to Ascochyta blight (AB) in advanced breeding and germplasm lines: One hundred and ninety seven AB promising advanced breeding and germplasm selections (36 ICRISAT bred lines, 23 germplasm lines, 42 lines from ICARDA, and 96 lines from Australia) were evaluated for AB resistance under controlled environment conditions. Eighty-five lines (18 ICRISAT bred lines, 7 germplasm lines, 24 ICARDA lines, and 36 lines from Australia) were found to be moderately resistant (3.1 to 5 rating on 1 - 9 scale) to AB. Susceptible cultivar Pb 7 showed had a damage rating of 9.0.

Suresh Pande and PM Gaur

ICAR-ICRISAT collaborative research on AB resistance: In collaboration with Indian Institute of Pulses Research (IIPR), Kanpur, 171 lines (101 IVT entries, 27 AVT entries, 20 entries form AB nursery, and 23 from BGM nursery) were evaluated for AB resistance under controlled environment conditions. Among the IVTs, IGLS 9, IGEB 6 and IGEB 7 were moderately resistant to AB (<5 rating on 1 - 9 rating scale). In the AVT group, AGK 4 (AVT 1 Kabuli) was found to be moderately resistant (3.1 to 5 rating). None of the entries in BGM and AB nurseries was found to be resistant to AB.

Suresh Pande and /Collaborators

Australia-ICRISAT collaborative research for AB resistance: In collaboration with the Center for Legumes in Mediterranean Areas? (CLIMA) and the Council of Grain Growers Organization (COGGO), Australia, 113 chickpea advanced breeding lines were evaluated for AB resistance following standardized screening technique using controlled environment facility at ICRISAT, Patancheru, India. Among the advanced breeding entries, ICGV 05558, ICGV 05562, ICGV 05563, ICGV 05564, ICGV 05565, and FLIP 94508C) were found to be resistant (<3 rating on a 1 - 9 rating scale), and 86 entries showed a moderately resistant reaction (3.1 to 5 rating). Segregating F_3 population involving 38 crosses (a total of 9225 plants) and F_4 generation involving 10 crosses (2430 plants) were also evaluated for AB resistance under controlled environment conditions. A total of 3248 single plants from the F_3 generation and 427 plants from the F_4 generation were free from disease, and were advanced in the field. Single plants from eighth crosses (1066 plants from F_3 generation) of the above material, which were planted in the field, were also evaluated for resistance to AB. Data on severity of AB was recorded at 10 days after inoculation (DAI) on a 1 - 9 rating scale. No resistance (<3 rating) was observed in any of the plants tested. However, out of 1066 plants tested, 196 single-plants showed a moderately resistant reaction.

Suresh Pande, PM Gaur and KHM Siddique

Identification of new sources of resistance to BGM in advanced breeding and germplasm selections: Sixty advanced breeding lines, 124 entries from preliminary and advanced yield trials, 40 entries from international screening nurseries, 58 Ascochyta blight promising entries, seven BGM promising selections, 131 crossing block entries, 332 BGM promising lines (83 ICRISAT bred lines, 154 germplasm lines, and 95 lines from Australia) were evaluated for resistance to BGM under controlled environment conditions. Susceptible cultivar JG 62 was found to be highly susceptible, and had a rating of 9 on a 1 - 9 rating scale.

Only ICCV 97653 was found to be resistant (3 rating). Of the 60 advanced breeding lines, 36 were moderately resistant to BGM. Seventy entries from yield trials, 20 from international screening nurseries, 32 from Ascochyta blight selections, five from BGM selections, and 78 from the crossing block entries were found to be moderately resistant to BGM. Of the 332 promising selections, 139 lines (26 from breeding lines, 58 from germplasm lines, and 55 lines from Australia) were moderately resistant to BGM.

Suresh Pande and PM Gaur

ICAR-ICRISAT collaborative research on BGM resistance: Twenty-three entries received from IIPR, Kanpur, Uttar Pradesh, India, were evaluated for resistance to BGM using standardized protocols in controlled environment facility. NBG 4, NBG 8, NBG 9, NBG 10, and NBG 21 were found to be moderately resistant (DR 3.1 to 5 on a 1 - 9 rating scale) to BGM.

Suresh Pande and NARS Collaborators

Australia-ICRISAT collaborative research on BGM resistance: Sixty of the 113 advanced breeding entries, which were evaluated for AB, were also evaluated for BGM resistance under controlled conditions, of which 36 were found to be moderately resistant to BGM.

Suresh Pande, PM Gaur and KHM Siddique

Milestone: 10 - 15 Kabuli chickpea breeding lines with extra large seed (>50 g 100 seeds^{-1}) and high resistance to FW developed (PMG/SP/HDU) 2009

Identification of FW resistant extra-large seeded Kabuli chickpea germplasm: There are many sources with high levels of resistance to FW in Desi chickpea, while resistance in Kabuli types is limited. Desi x Kabuli crosses have been widely used at ICRISAT for enhancing FW resistance in Kabuli chickpeas. However, most Kabuli varieties that involved one or more Desi parents in the pedigree have a brown tinge in seed color, e.g., Swetha (ICCV 2), KAK 2 (ICCV 92311), JGK 1 (ICCV 92337), and Vihar (ICCV 95311), while the market prefers cream to white (zero tannin) seed color in Kabuli chickpea. Thus, it is important to identify additional sources of FW resistance in Kabuli chickpea, particularly in the large-seeded category, so that large-seeded Kabuli varieties with resistance to FW and typical Kabuli type seed (ram's head shape and white seed color) can be developed from Kabuli x Kabuli crosses.

We selected 50 large-seeded Kabuli chickpea germplasm lines from ICRISAT's gene bank and evaluated them for agronomic traits at ICRISAT-Patancheru during 2004/05 post-rainy season. From these, 12 accessions having seed size of more than 50 g 100-seeds^{-1} were selected for further evaluation. During the 2005/06 post-rainy season, one set of these genotypes was grown in wilt sick plot for screening against FW, and another set in wilt free area for evaluation of agronomic traits. Two accessions, ICC 14194 and ICC 17109, originating from Mexico, showed complete resistance (0% plant mortality) to FW, whereas other lines showed 11 to 100 % plant mortality (Table 1). The resistant control (WR 315) had no plant mortality, whereas the early-wilt susceptible check (JG 62) had 100%, and the late-wilt susceptible check (K 850) had 87% mortality. Both the resistant accessions had pinnate (fern) leaf, which is common leaf type in chickpea. ICC 14194 was very early (97 days), while ICC 17109 was medium maturity (115 days). Two accessions (ICC 14194 and ICC 14198) were very early (days to maturity <100 days) and had 50 to 53 g 100 seeds^{-1}, suggesting that it is possible to breed early maturing Kabuli varieties with extra-large seed with FW resistance and typical Kabuli type seed.

Table 1. Morphological and agronomic characteristics of twelve extra-large Kabuli chickpea germplasm lines (ICRISAT, Patancheru, 2005/06 post-rainy season).

Accession	Origin	Leaf type	Days to flower[1]	Days to mature[1]	100-seed mass (g)[1]	Wilt reaction (%)[2]
ICC 7344	Mexico	Pinnate	38	100	50.2	95.2
ICC 8155	USA	Simple	45	112	62.2	100.0
ICC 11742	Chile	Pinnate	64	130	51.9	86.4
ICC 11883	Spain	Pinnate	56	130	58.7	90.9
ICC 13821	Ethiopia	Simple	50	118	51.0	92.0
ICC 14194	Mexico	Pinnate	38	97	52.9	0.0
ICC 14195	Mexico	Simple	50	109	60.2	52.2
ICC 14198	Mexico	Pinnate	42	94	50.2	70.8
ICC 14202	Mexico	Pinnate	46	118	58.1	75.0
ICC 15576	Mexico	Pinnate	52	120	55.6	81.0
ICC 16670	USA	Simple	45	110	50.1	11.1
ICC 17109	Mexico	Pinnate	46	115	63.2	0.0
WR 315 (Resistant check)	India	Pinnate	44	102	13.5	0.0
K 850 (Late wilting susceptible check)	India	Pinnate	56	109	28.9	87.0
JG 62 (Early wilting susceptible check)	India	Pinnate	42	103	15.8	100.0

[1]Data from crop grown in wilt-free field.
[2]Data on resistance to race 1 of *Fusarium oxysporum* f. sp *ciceris* from wilt screening nursery.

PM Gaur, S Pande and HD Upadhyaya

Development of extra-large seeded Kabuli chickpea breeding lines: A total of 88 Kabuli x Kabuli crosses were advanced by two generations (F_2 and F_3) for development of extra-large seeded (>50 g 100 seeds^{-1}) Kabuli breeding lines with resistance to FW. One of the parents involved in the crosses was a released cultivar (ICCV 2, KAK 2, JGK 1, or Vihar) with a seed size between 25 - 40 g 100 seeds^{-1} and the other parent was a extra-large seeded (>50 g 100 seeds^{-1}) Kabuli germplasm line, including the FW resistant lines ICC 14194 and ICC 17109. The F_2s were grown during the 2005/06 cropping season, and F_3s as a second crop during February to April 2006. The F_4 seed of eight of these crosses, which involved ICC 14194 and ICC 17109 as one of the parents, were supplied to 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, India) for screening against FW races prevalent in those regions, and selection of single plants for development of new progenies.

PM Gaur, S Pande and CLL Gowda

Association of leaf type, seed size, and seed yield in Kabuli chickpeas: As several of the extra-large seeded Kabuli germplasm lines have simple (unifoliate) leaf, we conducted an experiment to study the relationship of pinnate (fern) and simple leaf traits with seed yield and seed size. Three crosses; ICCV 2 × ICC 14195, ICCV 2 × ICC 14215, and ICC 16644 × ICC 16670 were selected in which the parents differed for leaf type and seed size. ICCV 2 and ICC 16644 have pinnate leaf and medium seed size (23 - 25 g 100 seeds^{-1}), while ICC 14195, ICC 14215, and ICC 16670 have simple leaf and large seed size (50 - 59 g 100 seeds^{-1}). The F_2 populations from these crosses were grown during the post-rainy season 2005/06. There were 226 plants in ICCV 2 × ICC 14195, 247 plants in ICCV 2 × ICC 14215, and 244 plants in ICC 16644 × ICC 16670 cross. Observations were recorded on leaf type, number of pods per plant, number of seeds per plant, 100 seed weight, and seed yield per plant. In each cross, the F_2 plants were classified into two groups based on leaf type (pinnate-leaved and simple-leaved) and then mean value of each trait was calculated for each group.

The pinnate-leaved plants gave significantly higher seed yield (53% in ICCV 2 x ICC 14215, 59% in ICCV 2 x ICC 14195, and 74% in ICC 16644 x ICC 16670) than the simple-leaved plants, mainly because of higher number of pods per plant. On an average, the pinnate-leaved plants produced 23 - 31 pods per plant, whereas simple-leaved plants produced 14 - 19 pods per plant. The increased number of pods per plant in pinnate-leaved plants resulted in increased number of seeds per plant and ultimately increased yield per plant. Seed size of pinnate-leaved plants and simple-leaved plants did not differ significantly in any of the crosses. The results clearly established negative effect of simple leaf traits on seed yield. Thus, it is recommended that selections should be practiced for pinnate-leaved plants in crosses involving simple-leaved and pinnate-leaved types.
PM Gaur/S Srinivasan

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: One hundred advanced breeding lines, selected primarily based on resistance to AB, BGM, and seed size were evaluated in two sets (Set A and Set B) of 50 each. In Set B, seed was not enough for a replicated trial. The 50 lines in Set-A were grown in a replicated trial along with 10 controls, which included the promising cultivars/breeding lines from Western Australia (Sona, Moti, Sonali, Rupali, WACPE 2078, WACPE 2098, WACPE 2099, and ICCV 96836) and India (JG 11 and ICCV 10). The trial was sown in a RCBD with 3 replications. Each plot consisted of 4 rows, 4 m long, and the plants were 30 cm apart. Central two rows were used for recording grain yield and plant biomass. The entries were screened against FW in a wilt-sick nursery, and for AB and BGM under controlled environment conditions. Nine breeding lines (ICCV 04512, ICCV 04513, ICCV 05527, ICCV 05528, ICCV 05529, ICCV 05530, ICCV 05531, ICCV 05532, and ICCV 05533) were resistant to FW (<10% plant mortality), AB (score between 3.0 - 4.0), and BGM (score between 4.0 - 5.0) (Table 2). Most breeding lines had a good seed size, but were late in maturity. These lines may perform well in long-season environments. Efforts are being made to improve these lines for earliness.

Table 2: Desi chickpea breeding lines with combined resistance to FW, AB, and BGM (ICRISAT, Patancheru, 2005/06 post-rainy season).

Entry	Days to maturity	100 seed wt. (g)	Seed yield (kg ha^{-1})	FW mortality (%) (2005)	AB score (mean of 2005 & 2006)	BGM score (mean of 2005 & 2006)
ICCV 05532	114	21.5	1732	6.8	3.50	4.3
ICCV 04513	121	19.1	1850	7.3	3.50	4.9
ICCV 05529	112	21.6	1914	3.6	3.58	4.2
ICCV 05531	112	21.2	2128	5.3	3.58	4.3
ICCV 04512	119	19.1	1829	7.8	3.58	4.9
ICCV 05530	114	22.1	1811	0.0	3.67	3.8
ICCV 05533	113	20.1	1863	0.0	3.75	4.7
ICCV 05528	114	22.4	1867	1.1	3.83	4.8
ICCV 05527	114	20.9	1768	5.9	3.83	4.7
Australian Checks						
Sonali	100	13.4	1906	90.3	4.67	7.2
Rupali	103	11.1	1336	67.5	4.58	8.2
WACPE 2078	103	15.9	1281	50.3	5.25	5.7
WACPE 2098	-	-	-	59.3	4.67	7.2
WACPE 2099	-	-	-	57.8	3.83	5.8
Moti	-	-	-	69.6	5.33	5.0

Entry	Days to maturity	100 seed wt. (g)	Seed yield (kg ha^{-1})	FW mortality (%) (2005)	AB score (mean of 2005 & 2006)	BGM score (mean of 2005 & 2006)
Sona	100	15.3	1232	84.0	7.00	5.4
ICCV 96836	110	13.2	942	55.3	5.00	5.8
Indian Checks						
ICCV 10	108	15.4	1963	15.5	7.58	6.0
JG 11	100	21.5	2756	5.2	5.50	5.2
SE ±	1.5	0.44	157.5			
CV (%)	2.4	3.83	16.9			

New breeding materials are being generated to develop breeding lines with resistance to multiple diseases. During the post-rainy season 2005/06, 60 F_2, 28 F_3, and 10 F_4 populations were grown. The F_3 and F_4 populations were screened for AB resistance under controlled conditions and the resistant plants were transplanted in the field. The resistant plants from F_4 populations of 12 crosses and F_3 populations of 33 crosses were screened for AB resistance and the resistant plants were transplanted in the glasshouse. Over 1,000 single plants were harvested and examined for seed size, shape, and color. A total of 110 plants were selected for further evaluation and also shared with Department of Agriculture and Food, Western Australia and Punjab Agricultural University, Ludhiana, India. A total of 37 new crosses were made during 2006 for development of breeding lines with resistance to multiple diseases. This included 28 intercrosses among the 10 selected F_4/F_5 progenies and nine single crosses. The single crosses included JG 11, Sona, Sonali, WACPE 2078, and WACPE 2099 as one parent, and ICCV 04512 or ICCV 05529 as the other parents.
PM Gaur/S Pande/CLL Gowda

Milestone: About 100 advanced germplasm and advanced breeding lines (Desi and Kabuli) screened for FW resistance (SP/PMG/HDU) 2009

Evaluation of advanced breeding and germplasm selections for resistance to FW: Eighty nine advanced breeding and germplasm lines were evaluated for resistance to wilt and root rots in a multiple-disease-sick-plot (MDSP) during the 2005/06 cropping season under artificial epiphytotic conditions. Susceptible early wilting cultivar ICC 4951 had 100% incidence within 30 DAS and the late wilting cultivar ICC 5003 showed 100% incidence within 90 DAS. Of the 89 advanced germplasm and breeding lines, KAK 2, ICCX 950106-F_4-40P-BP, ICCX 950106-F_4-43P-BP, ARFG 8, NNW 7, NNW 8, ICCX-970047-BP-BP-P27-BP, and ICCX 980068-F_4-P10-BP were asymptomatic (0%), while 80 lines showed a resistant reaction (<10% wilt incidence). Seven entries, KAK 2, NNW 19, ICCX 950151-F_4-50P-BP-BP, ICCX 950151-F_4-58P-BP-BP, ICCX 950151-F_4-31P-BP-BP, ICCX 950151-F_4-32P-BP-BP, and ICCX 950151-F_4-61P-BP-BP were free from collar rot and 69 entries had <10% collar rot incidence. PG 9421-1 was free from DRR, while 72 entries showed a resistant reaction (<10% incidence) to DRR. Resistance to collar rot and DRR will be confirmed under controlled environment conditions.

Suresh Pande and PM Gaur

ICAR-ICRISAT collaborative research on FW resistance in chickpea: In collaboration with scientists from Indian Institute of Pulses Resarch (IIPR), Kanpur, India 101 entries from IVT trials (26 entries from IVT-Desi, 28 from IVT-late sown, 20 from IVT-Kabuli, 20 from IVT rainfed, and 7 from IVT-extra bold), 48 from AVT trials (3 from AVT 1-Desi, 7 from AVT 1-late sown, 9 from AVT 1-Kabuli, 21 AVT 1- bold seed, 2 from AVT 1-rainfed, and 6 from AVT 1-high input), 10 donor lines, 9 chickpea wilt differential lines, and 46 from the national were evaluated for FW resistance under field conditions, and AB and BGM under controlled environment conditions. Of the 101 IVT entries, 23 were free from FW, while 30 were resistant (<10% incidence). Among the AVT entries, four (AIGB 15, AIGB 17, AIGB 19, and AIGB 21) were asymptomatic and six (AIGB 4, AIGB 5, AIGB 6, AIGB 12, AIGB 18, and AIGB 20 (showed a resistant reaction (<10% incidence). Of the 10 donors, D8 was resistant to FW. Among the wilt differential lines, D 05 was free from FW. NNW 5 and NNW 36 were asymptomatic and 10 lines were resistant.

Suresh Pande and NARS Collaborators

UAS Dharwad-ICRISAT collaborative research on wilt resistance in chickpea: Ninety-six single plant progenies (SPP) of the cross F_3 Bheema x ICCV 10, 106 SPPs of the cross F_3 M_2 Bheema x ICCV 10, 113 SPP of M_3 Bhima, five susceptible populations of the cross Bheema x ICCV 10, five resistant populations of Bheema x ICCV 10, five heterozygous populations of the cross Bheema x ICCV 10, and both the parents (Bheema and ICCV 10) were evaluated for wilt resistance under controlled environment conditions in the greenhouse. Susceptible cultivar JG 62 was included for comparison. High levels of resistance to wilt were observed in F_3 and M_3 populations, while no resistance was observed in susceptible, resistant, and heterozygous populations of the cross Bhima x ICCV 10.

Suresh Pande and PM Salimath

Milestone: Identification, characterization and resistance screening of potentially important diseases (DRR, BRR, CR) of chickpea (SP) 2008

Standardization of screening technique for collar rot (CR) resistance: Pure culture of collar rot fungus, Sclerotium rolfsii, was multiplied on three media; sterilized groundnut shells, sterilized sorghum straw (2 - 3 cm long pieces), and potato dextrose broth, and incubated at 25^0C for 20 days. Sclerotial production was estimated from 100 g ml^{-1} from each medium. About 10,245 sclerotia from groundnut shells, 5,074 from sorghum straw, and 1,853 from potato dextrose broth were recorded. Since the sclerotia are the main disease producing bodies in CR, groundnut shell medium was selected for further standardization of the screening technique. Thirty grams of inoculum (multiplied on groundnut shells) was mixed with 1 kg sterilized top 15 cm soil and filled in metal trays (70 x 30 x 16 cm). Light irrigation was given to make the soil moist and was left undisturbed for three days for the establishment of the fungus. Susceptible chickpea cultivar Annigeri was planted in rows in the trays and observed for 21 days for seed and seedling (collar) rot symptoms. About 21% of seed rotting and 79% collar rot was recorded at 21 days after sowing. Since the seed and seedling rots were consistent in three screenings in Annigeri, these trays were used for routine evaluation for collar rot resistance.

Evaluation of wilt promising selections for resistance to CR: Eighty-nine wilt promising advanced breeding and germplasm selections were evaluated for CR resistance following standardized sick tray technique under controlled environment conditions. None of the lines tested was found to be resistant CR. Therefore, we initiated systematic evaluation of germplasm accessions for CR resistance.

Suresh Pande

Milestone: Basic and strategic research on succession of Fusarium wilt and root rots of chickpea (SP) 2009

Threshold and quantification of fungal pathogens of chickpea in wilt and multiple disease sick plots: Quantification of fungal pathogens of chickpea wilt complex was carried out for the third year in the wilt sick plot (BIL 3 C), and the multiple disease sick plot [(MDSP) (BIL 1)] at ICRISAT, Patancheru, India. Collection of soil samples before planting and after harvesting of the crop and processing of soil was done as in the previous year. Number of fungal colonies g^{-1} soil was estimated using synthetic media (PDA and CDA) at 48 to 96 h after incubation. Number of sclerotia of *S. rolfsii* was quantified by using the rapid floatation technique.

Unlike previous years, the number of colonies of all the wilt complex pathogens was greater in the samples taken before sowing than after harvesting of the crop in both the fields. *Fusarium oxysporum* f.sp. *ciceris* (FOC) colonies were around 1,700 g^{-1} soil before planting and up to 4,150 g^{-1} soil after harvest of the crop in both fields. FOC colonies were recovered up to 80 cm depth before planting and up to 100 cm depth after harvest. In the wilt sick plot, in addition to FOC, other root rot causing pathogens (*Fusarium solani, Rhizoctinia bataticola,* and *Sclerotium rolfsii*) were negligible. This observation was in agreement with that of previous season.

Additionally, 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). About 475 colonies of *F. solani* and 220 colonies of *R. bataticola* g^{-1} soil, and four sclerotia of *S. rolfsii* 10 g^{-1} of soil were recovered from surface soil, which was collected before sowing of chickpea crop. These root rot pathogens multiplied during the cropping period and their population was almost double after crop harvest. Further, *F. solani* and *R. bataticola* 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 depth before sowing and 25 cm after harvest of the crop. Number of colonies of all these pathogens decreased as the depth increased. Lower number of propagules of the pathogens before sowing of the crop (October) may be due to absence of chickpea crop for about eight months in these fields. The phenomenal increase of the propagules at crop harvest (February) suggested that chickpea supports the multiplication of these pathogens in the soil.

Suresh Pande and Mamta Sharma

Succession of fungal pathogens of chickpea in wilt and multiple disease sick plots: Succession of occurrence of fungal pathogens in chickpea wilt and multiple diseases sick plots was studied during the season to confirm the results obtained in the previous year. Methodology including check cultivars (early wilting JG 62, late wilting L 550, and FW resistant WR 315), sampling and isolations on potato dextrose agar and czepek dox agar media were carried out as in the previous year. Isolations were made from root tip, root hair, epidermis and cortex, vascular bundles and collar region of apparently healthy looking plants at 10-day intervals from 10 DAS in both fields.

All the plants of cultivar JG 62 wilted within 30 DAS and that of L 550 in 80 DAS, while those of WR 315 remained healthy till maturity. FOC was found in all the root parts of healthy looking early wilting and late wilting cultivars from 20 DAS till the death of the plants. FOC was found only in root tip and root hairs in the resistant cultivar WR 315 at 50 DAS till maturity. This late infection and restriction of the fungus at the root tips in this cultivar may be due to its resistance to wilt pathogen. Black root rot pathogen, *Fusarium solani* and collar rot pathogen, *Sclerotium rolfsii* attacked and killed the plants in all the three cultivars at the seedling stage (up to 30 DAS) when the soil moisture was high. Warm temperature and soil moisture stress encouraged dry root rot fungus, *Rhizoctonia bataticola* (RB) to cause rotting of the roots. During the season, dry root rot appeared from 50 DAS till maturity in both late wilting and resistant cultivars. In both these cultivars, a mixture of FOC and RB was observed from 50 DAS till maturity indicating that interaction of both these pathogens may be responsible for death of the plants.

The FOC was dominant in the wilt sick plot throughout the cropping season, and recovered from all the root parts of apparently looking healthy plants of both JG 62 and L 550 from 20 DAS, and were present till the death of the plants. Susceptible cultivar JG 62 wilted in 30 DAS and L 550 in 80 DAS as in MDSP. Resistant cultivar, WR 315 yielded FOC only from root tips and root hairs from 60 DAS as in multiple disease sick plot. Additionally, a mixture of FOC and RB was also recovered from root tips of late wilting and resistant cultivars from 60 DAS till maturity. These results indicated that the death of the plants may be due to interaction of both these pathogens. Though wilt fungus is predominant in wilt sick plot, low intensities of *F. solani* and *S. rolfsii* at the seedling stage (up to 30 DAS), and *R. bataticola* during later stages were recorded in both L 550 and WR 315.

Suresh Pande and Mamta Sharma

Activity 6A.1.2: Develop chickpea breeding lines with, resistance to *Helicoverpa.*

Milestone: 5 - 10 resistance sources and advanced breeding lines tested for stability of resistance (HCS/CLLG/PMG) 2009

Breeding chickpeas for resistance to pod borer, *Helicoverpa armigera*: We evaluated 1,586 segregating progenies of chickpea during the 2005/06 season, and selected 1,161 progenies for further testing. The selection of progenies was based on visual scoring for pod damage and yield. Subsequently, progenies having <9% pod borer damage and high yield than the check varieties were selected for evaluation in the 2006/07 season. Eight hundred and fifty-five progenies (342 F_8 progenies and 315 F_9 progenies from single-crosses, and 198 F_8 progenies from four-way crosses) were sown to select lines for resistance to *Helicoverpa armigera* under natural infestation. Apart from this, we have sown F_2 diallel (71 entries, F_1's with parents having 64 entries), crossing block (54 entries) to develop new lines for resistance to this pest.

CLL Gowda, HC Sharma and P M Gaur

International Helicoverpa Screening Nursery: Using reliable field screening techniques developed at ICRISAT, several lines with resistance to *H. armigera* have been identified. The resistant (less susceptible) sources identified in field screening were used in crosses to transfer resistance into high-yielding varieties. A new set of lines was assembled for the international chickpea screening nursery *for H. armigera* (ICSN-HR) in 2006, including a few lines found to be less susceptible to *H. armigera.* 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 selection of material for use as parents or as end products suitable for local conditions. The trial with 25 chickpea genotypes, including two checks, was sent to six collaborators in India, and one to Myanmar.

CLL Gowda and HC Sharma

Stability of resistance to *Helicoverpa armigera* in chickpea: Twenty-five chickpea lines belonging to short- and medium-duration group (international *Helicoverpa* resistance screening nursery) were evaluated for resistance to *H. armigera* at different locations in India. There were three replications in a randomized complete block design. Data were recorded on leaf and pod damage rating and overall resistance score (1 = highly resistant, and 9 = highly susceptible), percentage pod damage, and grain yield. In the short-duration nursery, the lines RIL 115, ICC 14402, ICC 14559, ICCL 79037, and ICCX 73008 during the flowering stage, and RIL 115 and ICCL 79037 during the podding stage recorded less oviposition. Larval numbers were <8.3 in nine lines as compared to 54.0 larvae on the susceptible check, ICC 3137. The lines RIL 83, RIL 115, RIL 126, ICC 14402, ICL 86111, ICCX 73008, ICC 5383, and ICC 506 recorded an overall resistance score of <1.8. Grain yield of RIL 27, RIL 83, RIL 1, RIL 180, ICC 14559, ICCL 87322, and ICCC 37 was significantly greater than the susceptible or commercial checks in 4 or 5 locations. Based on insect damage parameters and grain yield, the lines RIL 27, RIL 81, RIL 83, and ICC 10613 may be used in chickpea improvement for resistance to *H. armigera*.

In the medium-duration nursery, low oviposition was recorded in RIL 51, RIL 85, RIL 169, ICCL 87314, ICCL 87315, ICC 67, Annigeri, and ICCV 10 in two or more locations, while the lines RIL 85, ICC 14559, ICC 162612, ICCL 87315, ICCL 87315, ICC 67, and Annigeri recorded low larval density in three or more locations. Low pod damage was recorded in RIL 51, ICC 14559, ICCL 87314, ICCL 87322, C 235, Annigeri, ICCV 10, and ICC 506. Grain yield was high in case of RIL 51, ICCL 87314, ICCL 87315, ICCL 87322, ICCV 10, and ICCC 37 in four or more locations. Principal component analysis placed the test genotypes into four groups, suggesting that there was a considerable diversity in chickpea genotypes to damage by *H. armigera*. Based on insect damage and grain yield, the lines RIL 51, ICCL 87315, ICCL 87322, ICCL 87315, and ICCV 10 may be used in chickpea improvement for resistance to *H. armigera.*

HC Sharma, CLL Gowda, PM Gaur and NARS partners

Milestone: Physico-chemical mechanisms of resistance to Helicoverpa identified and nature of inheritance studied (CLLG/HCS) 2012

Evaluation of protocols to screen chickpeas for resistance to pod borer, *Helicoverpa armigera*: A collaborative trial was conducted to evaluate the efficiency of screening for resistance to *H. armigera* using detached leaf assay (at the flowering stage), comparing pod damage and grain yield under protected and unprotected conditions under natural infestation, and caging the test entries with 20 pairs of adults at the flowering stage. Each entry was sown in 2 rows, 2 m long, and there were three replications in a RCBD. The crop was protected at the flowering and podding stages with methomyl (0.02%) in the protected plots. The genotypes ICC 10613, ICC 506 EB, and ICC 86111 showed antibiosis under lab conditions (detached leaf assay). DCP 92-3 and ICC 506EB showed antixenosis for oviposition under field conditions. The lines showing slow larval growth in the detached leaf assay also suffered low pod damage under natural infestation in the field (except PDE 2, which showed moderate antibiosis in the detached leaf assay). The genotypes ICC 506EB, ICCL 90034, JG 130, and PDE 2 yielded higher (1175 – 1307 kg ha^{-1}) than ICC 10613 (779 kg ha^{-1}) under protected conditions, of which ICC 506EB, ICC 90034, JG 130, and PDE 2 also performed well under unprotected conditions. Infestation of the test genotypes with adults in the cage resulted in poor infestation. Most of the eggs were laid on the nylon cloth. The results indicated that detached leaf assay provides a fairly good indication of expression of resistance to *H. armigera* in chickpea genotypes under field conditions.

Effect of egg age, storage duration, and temperature on egg hatch and incubation period of *H. armigera*: *Helicoverpa armigera* is used routinely as a tool for research on insect host plant interactions, biological, physiological, behavioral, and toxicity studies. Hence, manipulation of its life cycle can be used as a tool to have adequate numbers of insects at the appropriate stage of development for experimental purposes. Therefore, studies were undertaken to determine the effect of storage temperature on the duration and viability of eggs. Percentage egg hatch and incubation period were significantly influenced by egg age, storage temperature, and storage duration. Average egg hatch ranged from 0.0 to 96.8% across temperatures (-20 to 35^{0}C) and storage durations. None of the eggs hatched at -20 and 0ºC. Day degrees required for egg hatching decreased with an increase in temperature from 10 to 27ºC, and egg age from 0 to 3 days. The day degree requirements were highest for 0 day-old eggs at 10ºC, and lowest at 27ºC. It is safer to store *H. armigera* eggs at 10ºC for 10 days, with a hatchability of >75.0%, and an incubation period of <2 days.

HC Sharma and MK Dhillon

Physico-chemical mechanisms of resistance in chickpea to *Helicoverpa armigera*: Fifty morphologically diverse lines of chickpea were evaluated for resistance to the pod borer, *H. armigera* under field conditions. The material was sown in two sets of early- (30 lines), and medium-late-maturity (20 lines) along with appropriate resistance and susceptible controls. There were three replications for each trial in a randomized complete block design. Data were recorded on leaf damage rating at the vegetative stage, egg and larval numbers during the vegetative and flowering stages, overall resistance score (including recovery resistance), pod damage, and grain yield. In the early-maturity group, six lines showed a over all resistance score (1 = highly resistant, and 9 = highly susceptible) of <3.0 compared to 7.5 in JGM, 3.2 in ICCV 10, 3.0 in Vijay, and 5.0 in Vishwas. Of these, ICC 12475, ICC 4934, ICC 5434, and JGM 2 also had lower larval numbers during the vegetative, flowering, and podding stages, and showed an overall resistance rating of <3.0 compared to 6.0 in ICC 3137 and 1.0 in ICC 506. In the medium maturity group, the overall resistance scores ranged from 1.2 to 6.0, and the lines ICC 506, ICC 4934, ICC 5783, and JGM 4 showed resistance to *H. armigera* (damage score <2 compared to 6.0 in ICC 5002). Data have also been collected on the morphological traits, and the grain has been analyzed biochemically for protease inhibitor activity, protein profiles, nutritional composition, and acid exudates in leaves to identify physico-chemical factors associated with resistance to *H. armigera* in chickpea.

HC Sharma

Output target 6A.2: Molecular markers for AB and BGM resistance validated, and for Helicoverpa resistance identified in chickpea

Activity 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/RV) 2008

One intraspecific RIL mapping population is being developed from a cross between ICCV 04516 (resistant) and Pb 7 (susceptible). ICCV 04516 has a AB disease score of 3 - 4 (1 = immune, and 9 = highly susceptible), while Pb 7 is highly susceptible (diseases score of 9). About 300 F_2s of ICCV 04516 x Pb 7 were grown during the post-rainy season 2005/06. The F_3 progenies were grown during the off-season in greenhouse using single seed descent (SSD) method. Several plants died due to root rot and it was discovered that the pathogen-infected soil used in greenhouse was the cause of this disease. Hence, the population was discarded and the F_3 were grown from the remnant seeds.

PM Gaur and S Pande

Progress reported towards the achievement of milestone for 2008 will contribute towards achievement of the milestones listed below.

Milestone: The reported markers for AB and BGM resistance QTLs validated in other populations (PMG/SP/RKV) 2009

The work for this milestone will start after the development of mapping populations in 2008.

Milestone: QTLs for AB and BGM resistance introgressed in 3 - 4 farmer-preferred and locally adapted cultivars (PMG/SP/RKV) 2011

The work towards introgression of AB and BGM resistance QTLs will start after validation of these QTLs in 2009.

Milestone: Intra-specific and interspecific (C. arietinum x C. reticulatum) RIL populations for mapping Helicoverpa resistance developed and phenotyped (PMG/HCS) 2009

Evaluation of mapping population (ICC 506 x Vijay) for resistance to *Helicoverpa armigera*: The mapping population ICC 506 x Vijay (200 lines) was evaluated for resistance to *H. armigera* under natural infestation in the field. There were three replications in a randomized complete block design. Observations were recorded on leaf damage, numbers of eggs laid, larval density, number of pods, pods damaged, and grain yield. The overall resistance score (1 = highly resistant, and 9 = highly susceptible) ranged from 1.5 to 6.0 in the mapping population, 3.0 in Vijay, 1.3 in ICC 506, and 3.0 in ICCC 37. Percentage pod damage ranged from 5.2 to 29.8% in the mapping population, 10.5% in Vijay, 7.0% in ICC 506, and 17.4% in ICCC 37. The numbers of larvae at the reproductive stage were 1.3 to 13.3 in the mapping population, 6.7 in Vijay, 1.3 in ICC 506, and 7.3 in ICCC 37, indicating considerable variation in the susceptibility of the population and the parents to *H. armigera*. This population needs to be genotyped to identify molecular markers for resistance to *H. armigera.*

HC Sharma and PM Gaur

Milestone: One inter-specific (C. arietinum x C. reticulatum) RIL populations for mapping Helicoverpa resistance QTLs developed (PMG/HCS) 2009

RILs are being developed from an interspecific cross between ICC 3137 (*C. arietinum* - susceptible) and IG 72953 (*C. reticulatum* – resistant). The population was advanced by two generations (F_2 and F_3) in the greenhouse during 2006. Some plants died due to root rot disease as the soil used in the greenhouse was infected with the disease. New crosses were made between these parents and the F_1s were grown during the off-season in the greenhouse. The F_2 population from the new cross and F_4 progenies from earlier cross are being grown during the 2006/07 cropping season.

PM Gaur and HC Sharma

Milestone: QTLs for Helicoverpa resistance identified from C. arietinum x C. reticulatum RIL population (HCS/RKV/PMG) 2010

Newly developed SSR markers at ICRISAT are being screened on the parental genotypes of the mapping population to identify the polymorphic markers and integrate these into the genetic map.

RK Varshney

Milestone: Characterization of pathotypes of Fusarium oxysporum f. sp. ciceris, Ascochyta rabiei, and Botrytis cenerea in chickpea and Fusarium udum in pigeonpea (SP) 2009

Characterization of races of *Fusarium oxysporum* f.sp. *ciceris*: Chickpea lines identified to be resistant to wilt at one location often show a susceptible reaction at other locations mainly due to the existence of different pathotypes/races of the pathogen, *F. oxysporum* f. sp. *ciceris* (FOC). Our recent research on races of FOC indicated that the earlier (early 1980s) race scenario has changed. Hence, we initiated studies to collect races of FOC from major chickpea growing areas in India. A total of 38 virulent single spore isolates collected from 18 locations in 12 states in India were used for morphological, cultural, and pathogenic characterization of FOC. Of the 38 isolates, seven were collected from ICRISAT, Patancheru, two from Kurnool (Andhra Pradesh), four from Hisar (Haryana), one each from Dholi (Bihar), Delhi, Dhaulakuan (Himachal Pradesh), and Gulbarga (Karnataka), two from Junagadh (Gujarat), one from Sehore, four from Jabalpur (Madhya Pradesh), one from Akola, two from Badnapur, two from Rahuri (Maharashtra), two from Ludhiana, one from Gurdaspur (Punjab), three from Kanpur, one from Ghaziabad (Uttar Pradesh), and two from Pantnagar (Uttaranchal) (all in India). Four races, which were reported during 1982 from India were also included in this study.

Morphological variation: Five mm discs of actively growing five-day old culture of each isolate were transferred separately onto potato dextrose agar (PDA) medium in 90 mm plastic plates and incubated at 25^0 C for 7 days. Data on colony color, colony type, zonation, and colony growth (total growth and growth per day) were recorded at 7days after incubation. Based on type of mycelium, color, and colony growth; all the isolates were categorized into nine groups: FOCs 4, 8, 10, 16, 27, 32, 37, 38, and R4. Most of the isolates had cottony type of mycelium with erumpent growth. Isolate FOC 8 had submerged type of mycelium, FOC 16 showed effused growth, and isolate R4 had a pinkish mycelium.

Cultural variation: The nine isolates, which differed in apparent morphological characters, were used to study cultural characters. All the nine isolates were multiplied separately on potato dextrose broth medium and incubated at 25^0 C for 7 days. Data on percent micro and macro conidia, conidial size, and number of cells in macro conidium were recorded at 7 days after incubation. Considerable variation existed among the isolates in all the parameters studied. Percentage of micro-conidia was significantly more than macro-conidia in all isolates. Highest percentage of micro conidia (81.4%) in FOC 4 and lowest (51.6) in R4 was recorded. Largest micro-conidia (10.1x 5.5 μ m) were observed in FOC 38, and smallest (7.7 x 4.8 μ m) in FOC 8. Macro-conidia were larger (22.1 x 5.8 μ m) in the isolate R4, while they were smaller (14.9 x 5.5 μ m) in FOC 32. Mean number of cells in macro-conidia were 3.1 in FOC 10 and 4.6 in FOC 41.

Characterization of variability of *Ascochyta rabiei* : Differential reaction of cultivars to AB at different locations in India indicated the probable existence of races/pathotypes in the pathogen, *A. rabiei.* Hence, we initiated a systematic research to characterize races/pathotypes in *A. rabiei.* The *A. rabiei* infected chickpea plants were collected from 14 locations in different agroclimatic regions in India. Isolations were made from these infected plants and pure cultures of single spore isolates of *A. rabie* were obtained.

Morphological and cultural variation: Seven single spore isolates representing different agroclimatic zones were selected for studying morphological, cultural, and pathogenic characters. Five mm diameter discs from actively growing cultures of *A. rabiei* were placed at the center of 90 mm diameter petri plates containing CDA, and inoculated at 20^0 C. Colony color, intensity of the mycelium, colony diameter, number of conidiomata, and conidia were recorded. The *A. rabiei* isolates differed in morphology, colony color, colony size, pycnidial color (brown to slate grey), number of conidioamata (42.3 to 90.7 cm-^{2}), number of conidia (0.55 to 3.01 conidia 10^3 cm-^{2}), and conidial size (10.7 x 4.6 to 14 x 6.2 μm).

Pathogenic variation: All the 14 isolates were used for inoculation on 180 germplasm and advanced breeding lines under controlled environment conditions. All the 14 isolates of *A. rabiei* differed in their virulence pattern against 180 lines with AB 13 having maximum virulence index of 7.9 and AB 6 with a minimum index of 5.4 (Fig. 1). None of the lines were asymptomatic to any of the test isolates. Of the 180 lines, 10 lines to AB 6 and seven lines to AB 27 showed a resistant reaction. None of the entries were resistant to five isolates (AB 4, AB 17, AB 26, AB 1, and AB 13), whereas only one entry showed resistant reaction to four isolates (AB 8, AB 15, AB 3, and AB 18). Of the 180 entries, 15 entries (ICC 12, ICC 607, ICC 2165, ICC 3918, ICC 4200, ICC 4475, ICC 5124, ICC 6306, ICC 7002, ICC 13754, ICC 14911, ICCX 810800, ICCX 910028-39ABR-BP-10, ABR-BR, ILC 3870, and FLIP 82-258) differed significantly in their reaction to different isolates of *A. rabiei,* and hence were selected as differentials.

Characterization of variability of *Botrytis cinerea*: Thirty-two isolates of *B. cinerea* infecting chickpea, lentil, and marigold were collected from different locations to determine the variability of the fungus. Of the 32 isolates, 23 were collected from chickpea, 5 from lentil, 2 from marigold, 1 from Dahlia and 1 from grasspea. All the isolates were purified using BGM specific medium containing tannic acid. Preliminary analysis of eight Indian isolates using 20 RAPD primers (decamers) categorized them into two distinct groups. Detailed molecular analysis will be followed during 2007-08 season.

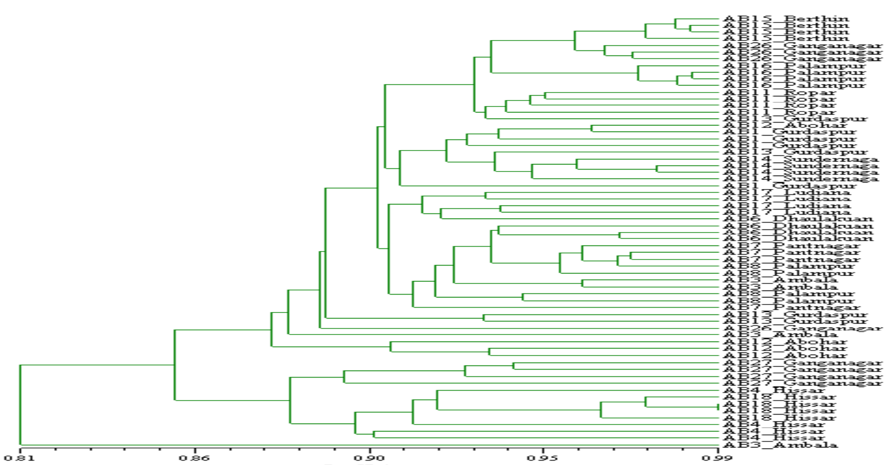


Fig. 1. Dendrogram showing the clustering of the single spore isolates of *A. rabiei* based on AFLP analysis;

Characterization of variability in *Fusarium udum* : We also initiated work on characterization of variability in *F. udum.* Eleven isolates of *F. udum* from nine locations in six states [Akola, Badnapur (Maharashtra); Bangalore, Gulbarga (Karnataka); Khargone (Madhya Pardesh), Muradnagar (Meerut), Varanasi (UP), Warangal and ICRISAT-Patancheru (Andhra Pradesh) all in India] were collected and single spore cultures were obtained using standard mycological techniques. All the single spore isolates once again were passed through common wilt susceptible cultivar ICP 2376 by following root dip inoculation technique, and aggressive isolates were stored at 4^0 C in the laboratory. Since the collection of the isolates did not represent the entire country, we continued to collect the isolates from pigeonpea growing areas. During the current crop season, wilt infected samples were collected from 9 locations (Yenagandla, Kulcharam, Jogipet, Andole, and Shivampet in Andhra Pradesh; Aurad in Karnataka; and Dhuki, Osmanabad, and Parbhani in Maharashtra, India). Isolations were made and *F. udum* was obtained from all the locations. All the cultures were purified and single spore isolates were obtained following standard mycological techniques. All these isolates were tested for virulence using a common susceptible cultivar ICP 2376 following root dip technique. All the virulent cultures were stored at 4^0 C in the laboratory.

Suresh Pande and Mamta Sharma

Milestone: Mapping of one intra-specific RIL population for dry root resistance conduced (PMG/SP) 2008

Mapping of RILs populations to DRR resistance under controlled environment: One hundred and twenty-six RILs and parents (JG 62 and ICCV 2) were evaluated for DRR resistance using paper towel technique under controlled environment conditions. Each entry was replicated thrice. Of the 126 RILs evaluated, ICCX 930111- 57-1-1-1-1SP-1-1-1-BP-1BP showed a resistant reaction (3 rating on 1 - 9 scale), while 15 entries were moderately resistant (3.1 to 5 rating). Both parents showed a susceptible reaction.
Suresh Pande/PM Gaur

Activity 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

In collaboration with Washington State University, Pullman, USA crossing program was initiated to cross perennial *Cicer* with annual as well as cultivated *Cicer*. Pollen germination was observed between intra-perennial *Cicer* species. It is possible to have successful pollination and fertilization between annual species *C. reticulatum* and perennial species *C. oxyodon* and *C nurstichacum,* as well as between cultivated chickpea and *C. oxyodon* and *C. nursticum*, but mature seeds were not observed. Since perennial *Cicer* does not set flowers at ICRISAT Patancheru, techniques were developed to preserve pollen of perennial *Cicer* for use at ICRISAT at a later date. Germination medium for annual and perennial *Cicer* pollen has also been developed.

Nalini Mallikarjuna and WSU partners

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

Cicer accessions ICC 17159, IG 73074, IG 72937, IG 72933, and IG 72934, which have shown resistance to Botrytis grey mold were used in the crossing program. Seed set varied depending upon the pollen parent used in the crossing program. The F_2 progenies from the crosses involving wild Cicer species IG 73074 and ICC 17159 are listed in Table 3. Chi square analysis of the progenies showed that the ratio of resistant to susceptible plants was 1: 3, and hence BGM resistance introgressed from wild Cicer was monogenic and recessive.

Table 3. Segregation of F_2 population for Botrytis gray mold resistance in interspecific derivatives of Cicer (ICRISAT, Patancheru, 2005/06 post-rainy season)

Cross	*Resistant*	*Susceptible*	*Ratio*	χ^2	*P*
ICC 4951 x IG 73074	***3***	***30***	***1:3***	***4.45***	***(0.05-0.01)***
ICC 4954 x ICC 17159	***1***	***38***	***1:3***	***10.5***	***(0.01-0.001)***
ICC 4954 x IG 73074	***12***	***51***	***1:3***	***1.19***	***(0.3-0.2)***
ICC 10136 x ICC 17159	***4***	***10***	***1:3***	***0.09***	***(0.8-0.7)***
ICC 10136 x IG 73074	***7***	***23***	***1:3***	***0.04***	***(0.9-0.8)***

Nalini Mallikarjuna and Suresh Pande

Progress reported towards the achievement of milestone for 2010 will contribute towards achievement of the milestones listed below.

Milestone: Ten advanced generation interspecific derivatives screened for Helicoverpa, AB and BGM in target locations in India (NM/HCS/SP/PMG) 2012

Milestone: Wild relatives with diverse mechanisms of resistance to Helicoverpa, AB, and BGM identified (HCS/SP/NM) 2009

Evaluation of wild relatives of chickpea for resistance to *Helicoverpa armigera:* We evaluated seven accessions of wild relatives of chickpea, along with resistant (ICC 506) susceptible (ICCC 37, ICC 3137, and L 550) lines of the cultivated chickpea for resistance to pod borer, *H. armigera* using detached leaf assay. Ten neonate larvae of *H. armigera* were released on fresh terminal branches of the test genotypes embedded in 3% agar-agar in 250 ml plastic cups. There were five replications in a completely randomized design. Observations were recorded on weights of the larvae on 10th day after initiating the experiment. The larvae weighed 41.3 to 61.6 mg per larva when reared on IG 70034 (*Cicer judaicum*), ICC 17148 (*C. microphyllum*), IG 70006 (*C. bijugum*), and ICC 69979 (*C. cuneatum*) compared to 74.2 to 79.6 mg on *C. reticulatum* (IG 72933 and IG 72953), 141.5 mg on Annigeri, 188.6 mg on ICC 506, 225.2 mg on L 550, and 222.3 mg on ICC 3137. The results suggested high levels of antibiosis to *H. armigera* in the wild relatives of chickpea belonging to the tertiary gene pool (*C. judaicum*, *C. bijugum*, *C. cuneatum*, and *C. microphyllum*), and moderate levels of resistance in the secondary gene pool (*C. reticulatum*), and low levels in the cultigen.

In another experiment, 12 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 assy. At five days after initiating the experiment, the larval weights were lower on ICC 69979, IG 70032, IG 70034, and ICC 17248 (<3.7 mg per larva under greenhouse conditions, and <4.98 mg under field conditions) as compared to the resistant and the susceptible checks (6.72 and 5.91 mg in ICC 506, and 12.89 and 13.84 mg in ICC 3137 under greenhouse and field conditions, respectively).

HC Sharma, SL Clement and TJ Ridsdill-Smith

Multiple disease resistance in wild *Cicer* accessions: One hundred and forty eight wild accessions belonging to seven *Cicer* species (30 accessions of *C. bijugum,* 3 accessions of *C. cuneatum,* 4 accessions of *C. echinospermum,* 47 accessions of *C. judaicum,* 27 accessions of *C. pinnatifidum,* 31 accessions of *C. reticulatum,* and 6 accessions of *C. yamashitae*) were evaluated individually for AB and BGM under controlled environment conditions. Of the 148 accessions, five accessions of *C. judaicum* (ICC 17211, IG 69986, IG 70030, IG 70037, and IG 70038) were found resistant (<3 rating on 1 - 9 rating scale), while 55 accessions were moderately resistant (3.1 to 5 rating on 1-9 rating scale) to AB. Two accessions IG 70037 and IG 70038 belonging to *C. judaicum* had a combined resistance (<3 rating on 1 - 9 scale), while three accessions of the same species (ICC 17211, IG 69986, and IG 70030) had a moderate resistance (3.1 to 5.0 rating) to AB and BGM.

Suresh Pande and Nalini Mallikarjuna

Output target 6A.4: Promising transgenic events of chickpea with proven resistance to *Helicoverpa* available for commercialization and introgression in locally adapted germplasm

Activity 6A.4.1: Develop transgenic events of chickpea for resistance to *Helicoverpa armigera* and evaluate their performance under contained greenhouse and field conditions

Milestone: 50 transgenic events of chickpea with Bt genes developed and screened in contained greenhouse (KKS/HCS/PMG) 2008

By using the axillary meristems as the ex-plant, *Agrobacterium* mediated genetic transformation of chickpea using *cry1Ac* and *cry1Ab* genes for resistance to *H. armigera* is being carried out by using the construct PBS 2310Ac carrying the *cry1Ac* gene. Thirty-five independent transgenic events have been produced and transferred to the greenhouse. Molecular characterization of these plants is underway. Chickpea transgenics carrying the *cry1Ab* gene are also being produced using the construct PHS 723 Bt. The construct contained *cry1Ab* gene under CAMV 35 promoter and *npt*II under *nos* promoter and polyadenylation sequence. About 40 independent transgenic events were transferred to greenhouse and the molecular characterization of these are underway. More than 30 are under the process of regeneration.

KK Sharma

Putative transgenic chickpea plants carrying *cry1Ab*, and *cry1Ac* genes evaluated for resistance to *Helicoverpa armigera* under greenhouse and field conditions: Six selections from over 50 transgenic events with *cry1Ac* gene produced at ICRISAT-Patancheru and Bose Institute, Kolkata, India (Under the IndoSwiss Project on Biotechnology) were bio-assayed for resistance to *H. armigera.* The plants were tested using the detached leaf assay in the laboratory. There were five replications in a completely randomized design. The detached terminal branches embedded in 3% agar-agar were infested with 10 neonate larvae in 250 ml plastic cups. Observations were recorded on leaf feeding (1 = <10% leaf area damaged, and 9 = >80% leaf area damaged), larval survival, and larval weights at 5 days after initiating the experiment. In the transgenic plants, leaf feeding scores ranged from 7.0 in ICCL 89314 Bt 2-4 to 8.8 in C 235 X 9-2 compared to 8.5 on the non-transgenic plants of ICCL 89314 and 7.8 on C 235. The larval weights ranged from 6.46 mg on C 235 X 6-5 to 8.37 mg on ICCL 89314 *Bt* 2-4 in the transgenic plants. The larval weights on the non-transgenic control were 7.99 mg on ICCL 89314 and 7.39 mg on C 235. The larval weights on the transgenic cotton were 1.99 mg compared to 9.6 mg on the non-transgenic control plants. The levels of expression in the transgenic chickpea plants appeared to be low, and we need to test new events to identify lines comparable to transgenic cotton in biological activity against *H. armigera*.

HC Sharma and KK Sharma

Progress reported towards the achievement of milestone for 2008 will contribute towards achievement of the milestones listed below.

Milestone: At least 8 promising Bt transgenic events of chickpea identified and insect resistance characterized under contained greenhouse conditions (KKS/HCS/PMG) 2009

Milestone: Three promising Bt transgenic events of chickpea identified and insect resistance characterized under contained field conditions (KKS/HCS/PMG) 2010

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

Milestone: Biosafety of transgenic plants to non-target organisms assessed (HCS/KKS) 2010

Effect of *Bt* toxins and transgenic plants on the survival and development of the parasitoid, *Campoletis chlorideae*, and the coccinellid predator, *Cheilomenes sexmaculatus*: We studied the influence of *Bacillus thuringiensis* (*Bt*) toxins and the *Helicoverpa*-resistant genotypes of chickpea on the survival and development of the pod borer, *Helicoverpa armigera*, and their indirect effects on the host specific parasitoid, *Campoletis chlorideae*. The foliar damage by *H. armigera*, larval survival, and larval weights were significantly lower on *Bt* sprayed chickpeas as compared to that on the untreated controls. The larval and pupal periods of the parasitoid, *C. chlorideae* reared on *H. armigera* larvae fed on different chickpea genotypes treated with *Bt* increased by 0.37 to 1.29 days and 0.19 to 0.58 days, respectively, as compared to those fed on untreated controls. The parasitoid cocoon formation was 18.7 to 38.7% on *H. armigera* larvae fed on *Bt* sprayed chickpeas compared to 69.3 to 77.3% on the untreated controls. Adult emergence was reduced by 61.1 to 83.8% over the untreated controls. There were no significant effects of *Helicoverpa*-resistant chickpea genotypes on the development and survival of *C. chlorideae*, suggesting that the *Helicoverpa*-resistant chickpea genotypes are compatible with this parasitoid. Larval weight of *H. armigera* showed a significant and positive association with *C. chlorideae* cocoon formation and adult emergence, and weights and size of male and female parasitoids (r = 74* to 99**), while significant and negative association was observed with larval period of *C. chlorideae* (r = -0.70*). The ELISA test indicated the presence of *Bt* protein in the *H. armigera* larvae fed on *Bt* treated chickpeas, while no *Bt* protein was detected in the larvae, cocoons, and adults of the parasitoid, *C. chlorideae* reared on *Bt* intoxicated *H. armigera* larvae, suggesting that lower survival of the parasitoid was due to poor quality of the host.

In another experiment, we studied the effects of cotton aphid, *Aphis gossypii* fed on *Bt*-transgenic and non-transgenic cottons on development and survival of the coccinellid, *Cheilomenes sexmaculatus*. The larval period of *C. sexmaculatus* reared on *A. gossypii* fed on *Bt*-transgenic cotton was prolonged by 1.5 to 2.0 days. The weight of *C. sexmaculatus* larvae was reduced by 3 to 4 mg when fed on *A. gossypii* reared in *Bt*-transgenic cotton plants. There was no effect of *Bt*-transgenic cotton fed aphids on larval survival, pupal period, and sex ratio of *C. sexmaculatus*. However, adult emergence decreased by 20 to 30% in coccinellids fed on *Bt*-RCH 2 and *Bt*-Mech 12 cotton hybrids as compared to those reared on non-transformed controls. The ELISA test indicated the presence of *Bt* protein in aphids, and the larvae and adults of the *C. sexmaculatus* fed on aphids obtained from *Bt*-transgenic cotton.

HC Sharma and MK Dhillon

Pigeonpea

Output 6A: Improved germplasm and varieties of sorghum, pearl millet, pigeonpea, chickpea and groundnut with pro-poor traits and associated advanced knowledge of selection tools and breeding methods made available to partners internationally

MTP Output Target 2006: New knowledge synthesized on seed production systems of improved lines, wild relatives and putative transgenics of pigeonpea, published and disseminated globally

Output target 6A.1: About 5 - 6 pigeonpea varieties with stable resistance to *Fusarium* wilt, sterility mosaic and *Helicoverpa* made available to NARS

Activity 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 multilocationally for their stability to wilt and sterility mosaic resistance in India (Annual) (SP)

Identification of stable sources of resistance to Fusarium wilt and sterility mosaic (SM): Pigeonpea lines found resistant to wilt and SM at ICRISAT, Patancheru were tested for wilt and SM resistance at different locations in India through the pigeonpea wilt and sterility mosaic disease nursery (PWSMDN) to identify stable and broad-based resistance to both these diseases. Thirty entries (28 wilt and SM resistant lines, and a susceptible check for each of the two diseases) were evaluated in 20 locations in India(Akola, Badnapur, Bangalore, Berhampore, Coimbatore, Dholi, Faizabad, Gulbarga, Hazaribagh, Hisar, ICRISAT, Patancheru, Kanpur, Khargone, Rahuri, Raipur, Sehore, SK Nagar, Pudukottai, Varanasi, and Warangal) during the 2005/06 cropping seasons. The experiment was planted in a wilt sick plot and inoculated with SM infested pigeonpea leaves using the leaf staple technique at two leaf stage or spreading SM infested twigs on test entries wherever possible. Data on wilt and SM was recorded twice, at flowering and at maturity stages of the crop.

Data was received from 13 locations. Wilt incidence in the susceptible check, ICP 2376 was high (> 60%) at Akola, Badnapur, Gulbarga, ICRISAT-Patancheru, Kanpur, Rahuri, and Sehore; while it was moderate at Bangalore and Warangal (~ 38%); and low in Khargoan (13%). There was no incidence at Berhampur, Hazaribagh, and Pudukottai (Vamban). Incidence of wilt in the local check was 83% (TTB 7) at Bangalore, 54% (LRG 30) at Warangal, 50% at Pudukottai, 10% at Hazaribagh, and no infection at Berhampur. The differential reaction of susceptible checks at different locations indicated the possible presence/existence of races/pathotypes of the wilt pathogen. This phenomenon needs detailed investigations to resolve the race scenario of *Fusarium udum* in India.

Of the 28 entries tested, 27 entries at Berhampur, 26 at Bangalore, 25 at Sehore, 24 at Akola, 23 each at Badnapur, ICRISAT, Patancheru, and Pudukottai, and <20 entries in rest of the locations were resistant to wilt. Four entries, ICP 7870, ICP 9174, ICP 9576, and KPBR 80-2-2-1 at 11 locations, six entries (ICP 8610, ICP 12749, ICP 12755, PR 5149, ICPL 87119, and V 71 A) in 10 locations, eight entries (ICP 12751, ICPL 93179, ICPL 96053, ICPL 96058, ICPL 96061, ICPL 99044, IPA 40, and KPBR 80-2-1) in 9 locations were resistant to wilt (< 10% wilt incidence).

Though data books were received from 13 locations, SM data was recorded only in nine locations. Susceptible cultivar ICP 8863 had >75% SM incidence at Bangalore, Badnapur, ICRISAT, Patancheru, and Rahuri; while it was moderate (31%) at Pudukottai, and low (10%) at Coimbatore. The SM was completely absent at Berhampur, Hazaribagh, and Sehore. Incidence of SM in local susceptible check was highest at Bangalore (100%), Badnapur (65%), ICRISAT-Patancheru (100%), and Rahuri (100%); moderate at Coimbatore (45%) and Pudukottai (46%), and low at Berhampore (4%). The differential reaction of susceptible checks at different locations indicated the possible presence/existence of races/pathotypes in the SM pathogen.

ICPL 99044 showed resistance at seven locations. Ten entries, ICPL 7870, ICPL 8610, ICPL 9576, ICPL 12957, ICPL 12759, ICPL 94062, KPBR 80-2-1, KPBR 80-2-2-1, V 71A, and V71B at six locations, 12 entries at five locations, and five lines at four locations were resistant.

Suresh Pande and 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 2009)

Fusarium wilt and SM resistance in advanced germplasm lines: Fifty-six lines (eight lines from advanced selections in 2003/04, four from advanced selections in 2004/05, and 44 selections from breeders material in 2005-06) were evaluated for combined resistance to FW and SM under artificial epiphytotic conditions at ICRISAT-Patancheru. Additionally, data on natural incidence of *Phytophthora* blight (PB), which occurred during the current season due to heavy rains in the months of July and August, were also recorded.

Both FW and SM susceptible cultivars showed >85% disease incidence. Of the eight advanced selections, six lines (BDN 2010, BSMR 846, MAL 3, PT 1037, PT 2033, and PT 2035) had a combined resistance (< 10%) to both FW and SM. Additionally, all these six lines had a very low (~ 1%) natural incidence of PB, and PT 1037 was free from FW. KPL 96053 and MA-S-DEO-74 were asymptomatic to both FW and SM, MAL 13 and MAL 23 were resistant to both diseases. These lines were also resistant to PB.

Among the 44 promising breeding lines tested, ICPL 20098, ICPL 20106, ICPL20116, and ICP 11376-5 were asymptomatic, and 26 lines resistant to both FW and SM. Additionally, eight lines were asymptomatic and 25 were resistant (<10%) to FW, while 14 were asymptomatic and 27 were resistant to SM.

Fusarium wilt and SM resistance in advanced breeding inbred lines: Seventy-four advanced breeding inbred lines were evaluated for resistance to FW and SM following standard field screening technique. Among the 74 entries, ICPL 99044 was asymptomatic and 41 lines were resistant (< 10%) to both FW and SM. ICPL 20127 and ICPL 20108 showed a resistant reaction to FW, while 14 lines were asymptomatic and 5 were resistant to SM.

Fusarium wilt and SM resistance in breeding populations: One hundred and forty breeding populations were evaluated for resistance to FW and SM under artificial epiphytotic conditions following standard field screening technique. Neither combined resistance to FW and SM nor resistance to FW was recorded in any of the lines tested. However, five lines were asymptomatic and 23 were resistant (< 0%) to SM.

Suresh Pande and KB Saxena

Fusarium wilt and SM reaction of *Helicoverpa* resistant lines: Thirty-five *Helicoverpa*-resistant lines were also evaluated for combined resistance to FW and SM under artificial epiphytotic conditions using the standard field screening technique. Natural incidence of PB was also recorded during this season. Among these lines, neither combined resistance to both diseases nor to FW alone was observed in any of these lines. However, two lines ICP 4983-4 and ICPL 20040 were resistant to SM (< 0% disease). Twelve lines (selections 4977-16-2, 4978-4, 4978-5, 4982-2, and 4983-11, ICPL 20042, ICPL 20045, ICPL 20058, ICPL 20060, ICPL 97249, ICPL 97250, and ICPL 97253) showed resistance (<10% incidence) to natural incidence of PB.

Additionally, *Helicoverpa* promising selections of the genotype ICPL 332 from 2002 to 2004 were also evaluated to FW and SM. All the selections showed a susceptible reaction to both FW and SM.

Suresh Pande and HC Sharma

ICAR-ICRISAT collaborative research on pigeonpea Fusarium wilt and SM: Under the ICAR-ICRISAT collaboration, 82 entries (65 entries from national nursery for AVT and 17 entries from national nursery of disease-resistant genetic stocks) from IIPR, Kanpur, were evaluated for FW and SM resistance under artificial epiphytotic conditions following standard field screening technique. Natural incidence of PB was also recorded on these lines during this season.

In the AVT, combined resistance to FW and SM was not found in any of the lines tested. However, combined resistance to SM and PB was identified in eight lines (JKM 208, JKM 186, IPA 15F, KAWR 91, KAWR 11, ICP 7035, BRG 3, and BRG 2-5). Seven entries (PT 8208-1, IPA 16 F, IPA 15 F, Bahar, ICP 7035, NTL 30, and IPA 8F) were asymptomatic, while 10 entries were resistant (<10%) to SM.

Among the entries in the national nursery for disease-resistant genetic stocks, one entry MAL 13 had a combined resistance to FW, SM, and PB. Nine entries (ICP 8862, ICP 9174, Azad, KPBR 80-2-1, DA 11, KPL 43, KPL 44, MAL 3, and MAL 6) were resistant (<10%) to SM and PB. Two entries (Azad and DA 11) to SM, and five entries (ICP 8862, ICP 9174, KPL 43, MAL 3, and MAL 13) to PB were asymptomatic.

Suresh Pande and NARS Collaborators

ANGRAU-ICRISAT collaborative research on pigeonpea FW and SM resistance: In collaboration with breeders and pathologists from ARS, Warangal (ANGRAU), F_2 to F_6 breeding populations and progenies belonging to11 crosses and 25 advanced lines were evaluated for FW and SM resistance under artificial epiphytotic conditions following standard field screening techniques. Among these lines, two progenies (entry numbers 129, 130) showed combined resistance to FW and SM. Several progenies of all 11 crosses were found resistant to SM. Of the 25 advanced lines, no line had a combined resistance to FW and SM, but 10 lines were found asymptomatic to SM.

Suresh Pande and S Vanisri

MAU-ICRISAT collaborative research on pigeonpea wilt and SM resistance: Nine entries received from Badnapur, Maharashtra, were evaluated for combined resistance to FW and SM under artificial epiphytotic conditions. Additionally, all these entries were also scored for natural incidence of PB. Of these, none was resistant to FW. However, BSMR 198 and BSMR 853 were asymptomatic, while BWR 2 and BSMR 846 showed a resistant reaction to SM. Additionally, five entries (BDN 708, BDN 2009, BSMR 198, BSMR 846, and BSMR 853) were also resistant to natural incidence of PB.

Suresh Pande and OD Kohire

Milestone: Molecular characterization of wilt/sterility mosaic resistant and susceptible germplasm/breeding lines for developing mapping populations with diverse genetic background (RKV/KML/KBS/DAH) 2009

A set of 32 pigeonpea genotypes with known resistance and susceptibility to several diseases (e.g. sterility mosaic, wilt, etc.) has been selected. DNA from these genotypes has been isolated. A set of 30 polymorphic SSR markers has been selected and optimized for screening 32 genotypes. The genotyping with the SSR markers is in progress. Subsequently, the genotyping data will be analyzed for understanding the genetic relationships among 32 lines and for selecting the best parental genotype combinations for generating the mapping populations with diverse genetic background, segregating for wilt, and sterility mosaic diseases.

RK Varshney, R Saxena, K Madhavi Latha, K B Saxena and D A Hoisington

Activity 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 along with resistant and susceptible checks for resistance to *H. armigera*. There were three replications in a randomized complete block design. Fifteen lines showed a DR of <4.0 compared to a DR of 2.8 in ICPL 332, 5.0 in ICPL 87119, and 8.7 in ICPL 87.

In another trial, we evaluated 8 newly developed varieties of pigeonpea along with ICPL 332, ICPL 84060, and ICPL 87 for resistance to *H. armigera* under protected and unprotected conditions. Data were recorded on pod damage by pod borer, pod fly, and pod wasp, and grain yield. Percentage pod damage was 46.8 to 62.1% in ICPL 97249, ICPL 97250, and selection numbers 4985-10, 4985-11, and 4989-7 compared to 60.7% in ICPL 332 and 100.0% in ICPL 87. The overall damage rating was 1.9 to 3.0 in ICPL 97249, ICPL 97250, and selection numbers 4985-4, and 4985-7 compared to 4.0 in ICPL 332 and 7.7 in ICPL 87, indicating improved levels of resistance to *H. armigera* in some of the newly developed lines.

HC Sharma and KB Saxena

Activities 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 pigeonpea and its wild relatives identified (HCS) 2009

Physico-chemical mechanisms of resistance to *Helicoverpa* in pigeonpea: Fourteen morphologically diverse lines of pigeonpea were studied for their interaction with *H. armigera* in the field. The genotypes ICP 12476, ICP 8102, and ICP 9879 suffered <40.5% pod damage by *H. armigera* compared to 40.8% in ICPL 332, 75.6% in ICPL 87, and 73.9% in ICPL 87119. These genotypes also had 49.6 to 58.4% healthy pods per plant compared to 66.7% in ICPL 332, 11.5% in ICPL 87, and 48.9% in ICPL 87119. Under laboratory conditions, weight gain by the larva at 7 days after initiating the experiment was 41.5 mg on ICP 15632, 128.4 mg on ICP 5529, 155.3 mg on ICP 13555, and 159.3 mg on ICP 11975 as compared 287.3 mg on ICPL 332 and 252.5 mg on 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.

HC Sharma

Milestone: Gene introgression from wild Cajanus into cultivated pigeonpea studied (NM/HDU/KBS) 2010

Cajanus acutifolius and *C. lineatus* from secondary gene pool of *Cajanus,* and *C. platycarpus* from tertiary gene pool were used in the crossing program. When used as a female parent, mature seeds were not obtained in case of *C. lineatus* and *C. acutifolius*, but the reciprocal of the cross was successful. It was possible to introgress male-sterility genes from *C. acutifolius*. Experiments are underway to introgress genes for resistance to *H. armigera*. The F_1 hybrid from the cross *C. lineatus* x ICPL 85010 is being grown in the glasshouse.

Nalini Mallikarjuna

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

A total of 11,565 plants from 2,067 selections made in 2005/06 were screened for resistance to *H. armigera* under unprotected field conditions. Twenty-five percent of the selections showed 20% or less damage, and 45% of the selections had 30% or less damage by *H. armigera* (Fig. 1). Progenies of the plant 8329 selected in 2003 continued to segregate for *H. armigera* resistance with 0 to 100% damage. Nearly 60 % of the progenies had <50% damage (Fig. 2). Another selection, 6028 had some progenies with little damage, and 50% of the progenies had less than 30% damage by *H. armigera* (Fig. 3).

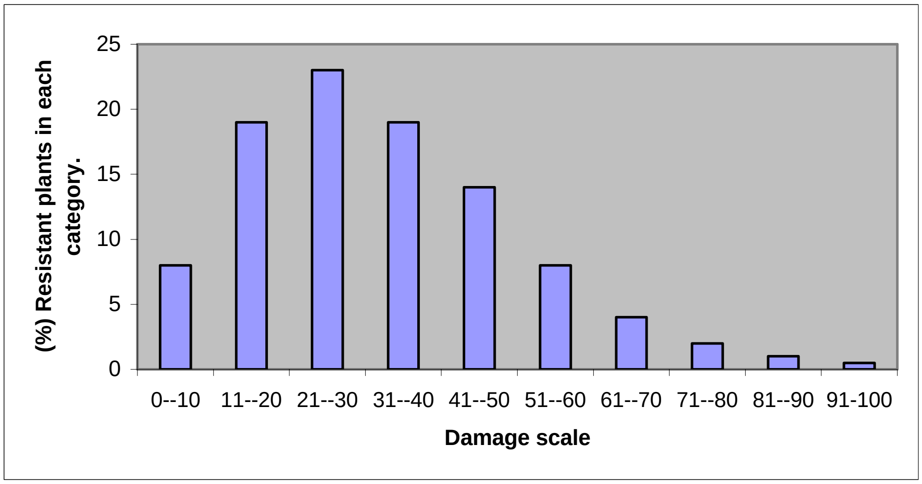


Fig. 1. Interspecific derivatives of pigeonpea (a total of 2067) evaluated for resistance to *H. armigera*

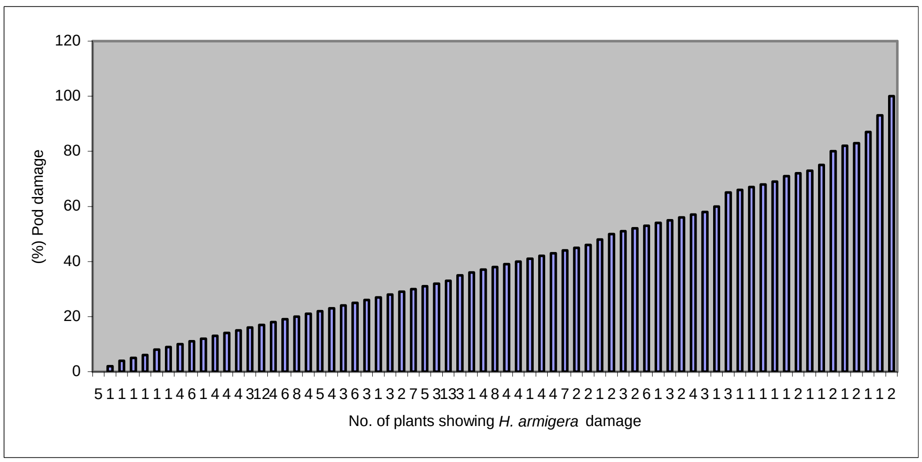


Fig. 2. Interspecific derivatives of pigeonpea (a total of 8329) evaluated for resistance to *H. armigera* (plant no. 8329)

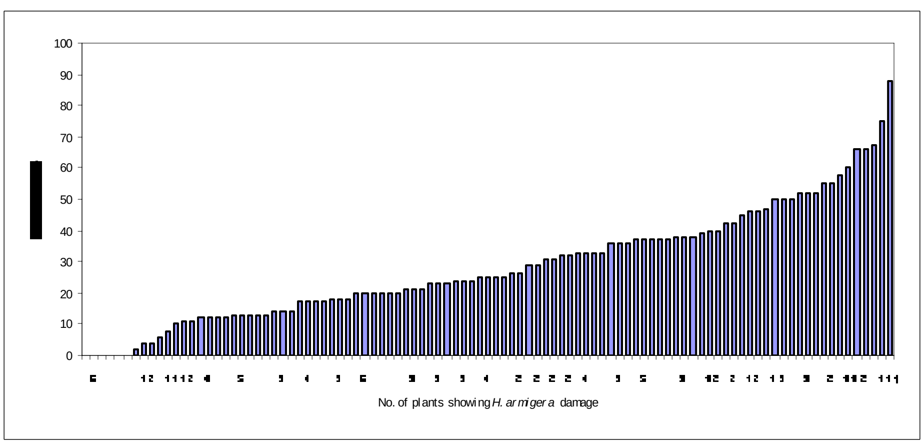


Fig. 3. Interspecific derivatives of pigeonpea (a total of 99) evaluated for resistance to *H. armigera* (plant no 6028)

Wide crosses for pod borer resistance in pigeonpea: To transfer the pod borer resistant gene(s) from *C. scarabaeoides* to cultigens, biparental mating between 38 *Helicoverpa*-resistant F_6 interspecific single plant progenies were attempted, and 17 F_1's were advanced to F_2 generation. A total of 78 F_2 single plant progenies of the cross ICPW 94-P1 x ICP 28-P1 were evaluated under controlled environment facilities.

HD Upadhyaya

Output target 6A.2: Promising transgenic events of pigeonpea with proven resistance to *Helicoverpa* available for commercialization and introgression in locally adapted germplasm

Activity 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/KBS) 2008

Transgenic pigeonpea plants were developed through *Agrobacterium tumefaciens*-mediated transfer of the Bt *cry1Ac* gene, and were evaluated for resistance to *H. armigera* under contained greenhouse and field conditions. Using seedling leaf petiole as the explant, a total of 50 independent transgenic events; 20 events of ICPL 88039, 25 of ICPL 87, and 5 of LRG 41 were produced and successfully transferred to the greenhouse. All these plants were characterized for the presence, integration, and expression of the *cry1Ac* gene by PCR, RT-PCR, Southern, IPCR and ELISA. A total of 35 (16 of ICPL 88039, 14 of ICPL 87, and 5 of LRG 41), and 20 (12 of ICPL 88039 and 8 of ICPL 87) events were advanced to T_1 and T_2 generations, respectively. These transgenic plants were evaluated for resistance to *H. armigera* in contained greenhouse conditions using leaf and pod bioassays. Larval survival and weights were found to be significantly less on 18 independent transgenic events in leaf bioassays. A contained field trial was conducted by using nine events of ICPL 88039 and nine events of ICPL 87 during the 2005 rainy season. In the leaf, pod, and inflorescence bioassays of the field grown transgenics, 5 events showed significant effect on weight gain by *H. armigera* larvae, but no significant effects on mortality were observed.

More events of pigeonpea transgenics with *cry1Ab* and *cry1Ac* genes are being produced using *Agrobacterium*-mediated transformation. Ten independent transgenic events with the *cry1Ab* gene have been transferred to greenhouse and are being characterized for the integration and expression of the transgenes. Over the course of next year, the development of at least 75 transgenic events with each gene are planned.

KK Sharma and HC Sharma

Milestone: Three promising Bt-transgenic events of pigeonpea identified and insect resistance characterized under contained field conditions (KKS/HCS/KBS) 2009

Putative transgenic pigeonpea plants carrying *cry1Ab*, and *cry1Ac* genes evaluated for resistance to *Helicoverpa armigera* under greenhouse conditions: Transgenic pigeonpea plants developed by introducing the synthetic *cry1Ac* gene through *Agrobacterium tumefaciens*-mediated genetic transformation were bioassayed for resistance to *H. armigera* using detached leaf assay. Each fully expanded leaf embedded in 3% agar-agar was infested with 10 neonate larvae of *H. armigera*. Data were recorded on leaf damage, larval survival, and weight gain at 5 days after initiating the experiment. The leaf damage rating ranged from 5.5 to 8.4, and larval survival from 70 to 86%. The weight gain by the larvae was 0.96 mg to 1.71 mg on 723 *Bt* 1-2-1-2, 723 *Bt* 2-1-1-1, 723 *Bt* 11-19, 723 *Bt* 1-2-1-2, 2310 Ac-0-3, 2310Ac-10-3, 2310Ac-20-1, and 2310Ac-15-4 compared to 2.41 mg on the non-transformed control plants of ICPL 88039. In case of transgenic plants derived from ICPL 87 using cry1Ac gene, the larval weights were 8.99 to 9.76 mg on the ICPL 87-12-1, ICPL 87-14-3, ICPL 87-23-3, ICPL 87-25-5, ICPL 87-12-1, and ICPL 87-3-2 transgenic plants compared to 9.48 mg on the non-transgenic ICPL 87 control plants and 13.69 mg on ICPL 87-5-1, suggesting that the effect of *Bt* protein on *H. armigera* was lower in plants derived from the susceptible cultivar ICPL 87 than the ones derived from the relatively less susceptible cultivar, ICPL 88039.

HC Sharma and KK Sharma

Progress reported towards the achievement of milestone for 2008 will contribute towards achievement of the milestones listed below.

Milestone: One to two Bt-transgenic events of pigeonpea used for introgression into locally adapted genotypes (KKS/HCS/KML) 2010

Milestone: Commercialization package for the introduction of pigeonpea with transgenic resistance to Helicoverpa armigera available for deployment (KKS/HCS/KML) 2011

Milestone: Biosafety of transgene products/transgenic events to non-target organisms investigated (HCS/KKS) 2010

Movement of *Bt* toxins through different trophic levels in the field: We monitored the movement of *Bt* toxin, Cry1Ac through different trophic levels in the field. A total of 40 insect specimens (25 from transgenic and 15 from non-transgenic cotton) were collected, and tested for the presence of *Bt*-toxin using qualitative ELISA at different intervals during the crop-growing season. Of the 25 insect species colleted from transgenic plots, 7 showed high levels, 9 showed low levels, and the remaining 9 had no Bt-toxin. Further studies on the sensitivity of different insect species to *Bt*-toxins and their uptake by the natural enemies are in progress.

HC Sharma and MK Dhillon

Output Target 6A.3: Twenty medium-long duration vegetable type pigeonpea germplasm/breeding lines made available

Activity 6A.3.1: Evaluation and selection of large pod medium – long duration germplasm and breeding lines for use as vegetable

Milestones: Research Bulletin on vegetable pigeonpea published (KBS) 2007

A Research bulletin on various aspects of vegetable pigeonpea including breeding and quality will be published in 2007.

KB Saxena

Milestones: At least 5-10 large seeded high-yielding vegetable type breeding lines and germplasm identified (KML/KBS/HDU) 2008

A number of large seeded vegetable types pigeonpea breeding and germplasm lines will be evaluated in vertisols for pod yield and seed of the selections will be made available for multilocation testing.

K Madhavi Lata, KB Saxena and HD Upadhyaya

Milestones: Genetically diverse large seeded vegetable type 10-15 breeding populations for further selection developed (KBS/KML) 2011

Genetically diverse vegetable lines will be crossed in 2007 rainy season to develop breeding populations for further selection and seed supply to NARS.

K Madhavi Lata and KB Saxena

Sorghum

Output A: Improved germplasm and varieties of sorghum, pearl millet, pigeonpea, chickpea, and groundnut with pro-poor traits and advanced knowledge of selection tools and breeding methods made available to partners internationally

MTP Output Target 2006: Sweet sorghum germplasm (500 lines) screened for Brix percentage and selected material available to NARS

Output target 6A.1: High biomass forage/sweet sorghum lines with tolerance to stem borer, 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 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

Milestone: Ten sweet-sorghum lines with high biomass and tolerance to stem borer and foliar diseases developed (BVSR/HCS/RPT/RS) 2007

A trial involving 30 varieties, including two checks, was conducted during the 2006 rainy season at the Agricultural Research Station (ARS), Gangavathi, Karnataka, India to ascertain the salinity tolerance and grain yield in large grain backgrounds. Eight varieties out-yielded the best check, ICSV 112 for grain yield and were comparable for grain size in the saline soils (10 dSm^{-1}) of ARS, Gangavathi. They will be evaluated for stalk yield, sugar content, tolerance to stem borer, and foliar diseases in the 2007 rainy season.

To improve the stalk and stalk sugar yield, the high tillering population (ICSP-HT) was mass selected for tillering ability, biomass, and height during the 2006 rainy season. From the population bulk, 220 male-steriles and 130 male-fertiles were selected. From SSV 74 F_3 crosses bulk, 38 male-steriles and 60 male-fertiles were selected, and from the SSV 84 F_3 crosses, 27 male-steriles and 98 male-fertiles were selected. The C_{11} population bulk introgressed with F_3 bulks of SSV 74 and SSV 84 was constituted by mixing the seed of male-steriles and male-fertiles in a 3: 1 ratio. These will be evaluated and advanced with selection in the 2007 rainy season. Similarly, the tall lines among them will be evaluated for tolerance to stem borer, foliar diseases, and for stalk and grain yield to be used as sweet sorghum varieties.

Based on the evaluation of sweet sorghum restorer parents, varieties and landraces in the 2005 rainy season, 36 lines were selected and evaluated along with the check, SSV 84 in the 2006 rainy season. Compared to the check, SSV 84 (1.8 t ha^{-1}), 19 lines with a grain yield range of 4.6 to 7.1 t ha^{-1} (on par with the control for sugar yield) were advanced. The performance of the selected five lines is given in Table 1**.**

Table 1. Performance of selected sweet sorghum restorers/varieties (at maturity stage) (ICRISAT, Patancheru, 2006 rainy season)

R-line/Variety	Days to 50% flowering	Plant height (m)	Grain yield (t ha^{-1})	Cane yield (t ha^{-1})	Juice yield (t ha^{-1})	Brix reading at maturity	Sugar yield based on Brix reading and juice yield (t ha^{-1})
SP 4487-3	83	3.2	7.6	83.6	41.0	18.3	7.1
SPV 422	84	3.3	7.2	75.4	38.4	19.0	6.9
SP 4484-1	83	3.4	5.6	82.5	38.1	18.5	6.8
SSV 53	80	3.2	8.9	76.9	36.6	19.2	6.7
SP 4482-2	82	3.4	5.2	76.0	40.4	17.0	6.7
SSV 84 (Check)	83	3.0	1.8	66.4	27.6	21.0	5.3
Mean	77	3.1	6.0	58.4	27.3	17.2	4.6
CV (%)	2.33	7.78	13.24	19.40	23.10	8.25	22.33
LSD (5%)	2.88	0.38	1.26	18.17	10.11	2.28	1.63

BVS Reddy

Milestone: At least 5 sorghum lines with large grain, high grain yield, and tolerance to shoot fly for post-rainy season adaptation developed (BVSR/HCS) 2008

In order to assess the farmers' selections in relation to breeders selection, a trial consisting of 9 (4 farmers and 5 breeders) post-rainy season adapted sorghum lines selected from F_7 generation were evaluated at ICRISAT, Patancheru; UAS Regional Agricultural Research Station, Bijapur; and Punjabrao Krishi Vidyapeeth, Akola (India) during the 2005/06 post-rainy season. Data were recorded for days to 50% flowering, plant height (m), staygreen score on a 1 to 5 scale at harvest (where 1 = >75% green, 2 = up to 75%, 3 = 26 - 50%, 4 = 10 - 25%, and 5 = <10% green leaf area), lodging score (on a scale 1 to 5 scale; where 1 = no lodging, 2 = up to 25% lodging, 3 = 26 - 50%, 4 = 51 - 75%, and 5 = >75% lodging), grain size (g 100^{-1}), and grain yield (t ha^{-1}). The CV for grain yield from Akola was very high, and hence the data from Bijapur and ICRISAT were combined and presented here. For grain size, data recorded at ICRISAT is presented. The mean grain yield of breeders' selections (3.7 t ha^{-1}) was marginally superior to that of farmers' selections (3.4 t ha^{-1}). However, for other traits (grain size, days to 50% flowering, and plant height) farmers' selections were similar to that of breeders' selections (grain size: 2.3 g 100^{-1}, plant height: 1.9m, and days to 50% flowering: 77 days). Breeders' selections were more tolerant to lodging (Table 2). From these results, it can be concluded that though farmers selections in the early generations had bolder grains (2005 archival report), with advancement in generations, breeders' selections had high grain yield with grain size similar to farmers' selections.

Table 2. Performance of sorghum varieties in Participatory Plant Breeding Trial (PPBT) (ICRISAT, Patancheru, and Bijapur, 2005 post-rainy season).

digree	**Grain yield (t ha^{-1})**	**Days to 50% flowering**	**Plant height (m)**	**Stay green score**	**Lodging score**	**100-grain weight (g) at ICRISAT**
Farmers' selections						
(M 35-1 × SPV 1359)-5-2-1-1-1-1	3.6	77	1.9	2.8	1.7	2.3
(M 35-1 × SPV 1359)-8-2-2-1-1-1	2.9	79	1.9	3.0	1.5	2.2
(M 35-1 × SPV 1380)-1-1-1-1-1-1	3.6	76	2.0	3.3	1.8	2.2
(M 35-1 × SPV 1380)-1-1-2-1-1-1	3.5	76	1.9	2.7	1.8	2.3
Mean	**3.4**	**77**	**1.9**	**3.0**	**1.7**	**2.3**
Breeders' selections						
(M 35-1 Bulk 2 × SPV 1359)-1-1-1-1-1-1	3.9	76	1.9	3.3	1.7	2.3
(M 35-1 Bulk 3 × SPV 1359)-4-1-3-1-1-1	3.1	77	1.9	3.0	1.0	2.6
(M 35-1 Bulk 3 × SPV 1359)-4-3-1-1-1-1	3.9	78	1.9	3.0	1.5	2.4
(NTJ 2 × SPV 1359)-5-2(Tan)-1-1-1-1	3.6	78	1.9	3.3	1.5	1.8
M 35-1-Bulk-3-29-3-1-1-1-1-1	4.3	76	1.9	3.0	1.3	2.4
Mean	**3.7**	**77**	**1.9**	**3.1**	**1.4**	**2.3**
Moulee (Check)	3.0	76	1.9	2.8	2.0	3.9
M 35-1 (Check)	3.0	76	1.8	2.5	1.2	3.7
CSH 15 R (Check)	4.4	76	1.9	3.0	1.3	3.4
Mean	**3.6**	**77**	**1.9**	**3.0**	**1.5**	**3.8**
SE ±	0.45	0.87	0.08	0.31	0.21	0.04
CV (%)	21.92	1.97	6.98	17.90	23.91	1.70

The advanced lines will be evaluated for shoot fly resistance. In another experiment, a total of 60 entries (selected based on their yield and large grain), including checks, were planted in RCBD with 3 replications for evaluation for grain yield and other agronomic traits during the post-rainy season 2006. The promising lines will be evaluated for shoot fly resistance in 2007.

BVS Reddy

Milestone: Ten high yielding grain mold tolerant sorghum lines developed for rainy season adaptation (BVSR/RS) 2010

New sources of resistance for grain mold will be obtained and selfed during 2006/07 post-rainy season. Crossing program will be initiated during 2007 rainy season using new sources of resistance to grain mold from germplasm and high yielding adapted B lines.

BVS Reddy

Activity 6A.1.2: Developing QTL mapping populations for economic yield components of sweet sorghum

Milestone: Two F_5 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

Contrasting parents, two sets each for biomass yield, sugar content, and sugar extraction characteristics have been identified. They will be used in crossing program in 2007 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

During the 2006 rainy season, plant x plant crosses were made, and F_{1s} and selfed parental plant seeds harvested. Pairs of genetically diverse (dissimilarity greater than 0.70 based on allelic variation detected at 67 polymorphic SSR loci distributed across 10 sorghum linkage groups), agronomically elite inbred parental lines differing in stem sweetness, salinity tolerance in both pot and field screens), and other agronomic characteristics were selected for making the crosses. Parental line pairs from which F_1 seed has been harvested included: BTx623 (salinity tolerant, non-sweet) x ICSR 93024-1 (salinity sensitive, sweet), BTx623 x S 35 (salinity sensitive, sweet), ICSV 93046 (salinity tolerant, sweet) x ICSR 93024-1, ICSV 93046 x SPV 1022 (salinity sensitive, somewhat sweet), ICSV 93046 x S 35, and SP 39105 (salinity tolerant) x ICSR 93024-1. The F_1 seeds have been sown in the 2006/07 post-rainy season.

SP Deshpande and CT Hash

Activity 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 post-rainy season adaptation developed (BVSR/HCS) 2008

During post-rainy season 2005-06, 13 lines adapted for post-rainy season (Moulee, M 35-1, IS 33844-5, M 35-1-19, M 35-1 bulk 1, 2, 3, 4, SPV-1359, SPV 1411, SPV 1380, Giddi Maldandi, and NTJ-2) were crossed to obtain the F_1s. The F_1s were grown in the 2006 rainy season and harvested separately. A total of 125 F_2s were planted during the post-rainy 2006 to undertake selections. The agronomically superior advanced breeding lines obtained will be screened for shoot fly resistance. In another experiment, 18 F_2s derived from crossing five dual season restorer lines (M 35-1-19, ICSR 93001, 92003, 93031, and IS 33844-5) were sown during the post-rainy 2006 to undertake selections. The advanced lines will be screened for SFR based on their agronomic performance.

BVS Reddy

Activity 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 (BVSR/RPT) 2009

A total of 120 F_5 progenies selected from the crosses of grain mold resistant landraces, high yielding B-lines, and grain mold resistant breeding lines were evaluated in advanced screening trial for grain mold resistance (GMR) during the 2006 rainy season. These progenies along with their test-crosses on known sources of A_1 and A_2 cytoplasmic male-sterile (CMS) systems-based male-sterile lines were also evaluated in a separate nursery in breeding block during the 2006 rainy season. The results on screening trial are awaited. A total of 64 lines with GMR (PGMR $\leq$ 5) and maintainer reaction were selected from the breeding block nursery. These included 60 white grain lines and four red grain lines. The time to 50% the flowering in these 60 white grain lines ranged from 52 - 80 days and plant height ranged from 1.0 - to 2.0 m.

BVS Reddy and RP Thakur

Output B. Annually 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

Groundnut

MTP output Target 2006: At least 15 new high yielding drought tolerant breeding lines made available to partners

Output target 6B.1: Develop groundnut varieties with tolerance to drought using conventional and biotechnological approaches

Activity 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

During the 2005/2006 post-rainy and the 2006 rainy seasons, 37 new crosses were made to generate populations for selection for resistance to drought and high pod yield with desirable agronomic traits. ICGV 05151, ICGV 06423, ICGV 01265, ICGV 03115, ICGV 95386, ICGV 03057, and ICGV 06443 were involved in hybridization.

Milestone: 5 - 10 new sources of resistance to drought identified (SNN/RA/VV) 2009

During the 2005/2006 postrainy season and the 2006 rainy seasons, 386 lines (along with controls) were evaluated in nine replicated yield trials, and 192 lines in 4 augmented trials. In the post-rainy 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 day intervals) starting from 65 days after sowing until harvest. The elite and advanced trials weree also grown with full irrigation in the same field to assess the full yield potential of the breeding lines included in these trials.

2005/2006 post-rainy season: In an elite trial (Spanish), ICGV 03064 (under stress - 3.1 t ha^{-1} pod yield and 61% shelling outturn; irrigated - 4.9 t ha^{-1} pod yiels, and 67 % shelling outturn) outperformed the best control ICGS 76 (under stress- 2.7 ± 0.26 t ha^{-1} and 67%; irrigated - 3.9 ±0.63 t ha^{-1} and 76%) under irrigated and stress conditions. It also significantly outyielded (rainfed - 4.9 t ha^{-1} and 60%; irrigated - 5.0 t ha^{-1} and 70%) the best control (rainfed: ICGV 00350 – 2.8 ± 0.21 t ha^{-1} and 67%; irrigated : ICGV 86325 – 4.8 ± 0.32 t ha^{-1} and 71%) in the 2005 rainy season.

2006 rainy season: In the new elite trial (Spanish), none of the entries outperformed the highest yielding control under both irrigated and rainfed conditions. In the new advanced trial (Spanish) evaluated under rainfed conditions, ICGV 05151, CGV 05155, CGV 05162, and CGV 05158 outyielded (3.3-2.9 ± 0.18 t ha^{-1}) the highest yielding control ICGV 87846 (2.3 t ha^{-1}). When this trial was evaluated under irrigation, the same four lines (4.2 - 3.9 ± 0.27 t ha^{-1}) outyielded the highest yielding control ICGV 87846 (2.9 t ha^{-1}). The best line came from (ICGV 99160 x ICGV 99240) cross. In the new advanced trial (Virginia) under rainfed conditions, 14 lines (3.7 - 2.8 ± 0.23 t ha^{-1}) significantly outyielded the highest yielding control ICGV 00350 (2.3 t ha^{-1}). Under irrigation, only ICGV 06424 (4.1 t ha^{-1}) outperformed the highest yielding control ICGV 87846 (2.3 t ha^{-1}). In the new preliminary trial (Spanish), 23 lines (3.8 - 3.2 ± 0.21 t ha^{-1}) outyielded the best control ICGV 02266 (2.6 t ha^{-1}). Best performer ICGX 020048 came from ((ICGV 99069 x ICGV 93184) x (ICGS 44 x ICGS 76)) cross. In the new preliminary trial (Virginia), 6 lines (3.5 - 3.0 ± 0.27 t ha^{-1}) significantly outperformed the best control ICGV 87846 (2.9 t ha^{-1}). The top line ICGX 020054 came from (ICGV 92069 x ICGV 93184) cross. Four lines (ICGV 03056, ICGV 03057, ICGV 03109, and ICGV 03115) were selected for inclusion in the international trials in the 2005/06 post-rainy season.

Milestone: 15 - 20 advanced lines tested in Anantapur in India and other drought prone areas (SNN/RA/VV) 2009

A special trial was formulated to develop 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 report 2005), we selected 16 lines for further evaluation at ICRISAT and ARS, Anantapur. At Anantapur, the trial could be sown only on 12 September 2006 as the monsoon was delayed during the 2006 rainy season. At

ICRISAT, 8 lines (2.6-1.6 ± 0.13 t ha^{-1}) outperformed the best yielding control TAG 24 (1.3 t ha^{-}) and 13 lines (2.6 - 1.4 ± 0.13 t ha^{-1}) significantly outperformed ICGV 91114 (1.0 t ha^{-1}). When the same trial was evaluated under irrigation, 7 lines (3.2 - 2.4 ± 0.16 t ha^{-1}) outperformed the highest yielding control TAG 24 (2.1 t ha^{-1}). The top seven lines were common in both the environments. The best line ICGV 06436 came from (TAG 24 x ICGV 86300) cross. In another trial, 7 out of 16 lines (2.9 - 2.1 ± 0.16 t ha^{-1}) outperformed the best control ICGV 00350 (1.7 t ha^{-1}) under rainfed conditions at ICRISAT. Under irrigation, none of the entries significantly outyielded the best control. The best entry ICGV 06456 came from (AK 12-24 x ICGV 99032) cross.

Milestone: Physiological traits in 3 – 4 superior sources for drought tolerance dissected (VV/SNN/RA) 2010

An experiment was carried out to test the effect of a water deficit applied at different stages (early flowering, late-flowering, and pod-filling) on pod yield and pod number. We used standard dry-down technique to apply the stress at these stages. At each stage, stress was imposed according to dry-down technique, whereby the WS set was re-watered when the relative transpiration was between 10 - 20% of control. We based the analysis on pod number per plant relative to control. Water stress at mid-pod filling stage had no large influence on the pod number relative to the control (pod number was 90% of control across genotypes), although a few genotypes such as ICR 48 and JUG 26 had relatively lower pod number under stress. By contrast, the relative pod number of plants exposed to stress at early- and late-flowering was 63 and 76% of that of control across all genotypes tested, with a fairly large variation across genotypes (35 - 93% for early-flowering stage, and 49 - 98% for late-flowering stage). During the early-flowering stage, the drought tolerant genotype ICGV 91114 was able to maintain 93% of control pod number.

Vincent Vadez

Activity 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/RKV) 2008

One population [ICGV 86031 (high TE) x TAG 24 (low TE)] has been phenotyped for two consecutive years for TE in pot experiments in outdoor conditions during the Feb - April. Transpiration efficiency (TE) data have shown a good agreement between years. Usual surrogates for TE [specific leaf area(SLA), and Spad chlorophyll meter reading (SCMR), and the carbon discrimination ratio, $\Delta^{13}C$] have shown poor relation with the TE values, indicating that, though the use of these surrogates remains valid to carry out large scale screening of germplasm, they have to be used carefully for phenotyping, and measurement of TE itself is advised.

The parental genotypes of the mapping population were screened with >500 microsatellite markers and the polymorphic markers were identified. Genotyping of the mapping population has been initiated. Based on genotyping data of >50 markers on the population, a preliminary map-free linkage analysis has been undertaken. The analysis revealed a few markers linked to TE, and to several surrogates (SCMR). However, these markers explained 10% of the phenotypic variation. A larger number of markers would be needed in groundnut, as well as a larger range of variation in TE, to find out robust QTLs for TE. In this direction screening of the parental genotypes with a larger number of markers and genotyping of the mapping populations with more polymorphic markers is in progress.

Vincent Vadez, Rajeev Varshney and L Krishnamurthy

Milestone: Mapping populations between contrasting parents developed to identify QTLs for component traits of drought tolerance (root traits) (VV/RA/SNN) 2009

Screening for TE was undertaken in 2006 on 440 genotypes, including the mini-core collection of groundnut, which showed over 5-fold variation for TE. This range is higher than the variation observed in 45 lines tested previously (mostly breeding lines) to identify contrasting parents for TE, from which 2 segregating populations for TE have been developed. Similarly the germplasm collection was genotyped with 21 microsatellite markers to assess the molecular diversity. In a subset of the germplasm (189 accessions), the microsatellite markers yielded 3 to 20 alleles with an average of 12.4 alleles per marker with an average PIC value of 0.84. A repeat of the TE screening will be performed. Subsequently the molecular diversity data together with the trait diversity data will be analyzed and the candidate genotypes with a greater TE and genetic diversities will be identified to develop new populations for TE.

Vincent Vadez, Rajeev Varshney and L Krishnamurthy

Milestone: Range of variations for root traits assessed in groundnut germplasm (VV/SNN/RA/HDU) 2008

Measurement of root traits, though better and more easily done in a controlled cylinder system, remains a time consuming exercice, with large error component, using destructive sampling, and providing "static" data that does provide little information about the actual activity of roots and the kinetics of this activity. In the end, more than the roots, water uptake and the kinetics of water uptake to cope with terminal drought are important. We used 4 groundnut genotypes and grew them in 1.2 m PVC cylinders with 16 cm diameter. 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 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. Water loss in WW plants was adjusted to the cylinder weight 3 days after imposing the treatment. The process of weighing the cylinders was relatively simple and rapid. Data showed that 5 days after stress imposition, normalized TR (NTR) was about 50% of controls. Thereafter, and until harvest at 17 days after treatment imposition, NTR of TMV 2, a genotype known to be drought-susceptible, was 20 % lower than TAG 24 and ICGS 44 (these 2 genotypes are known for deep and profuse rooting). At 17 days after stress imposition, TMV 2 plants were permanently wilted whereas TAG 24 and ICGS 44 were not. Total transpiration values from the time of treatment imposition were similar in TAG 24 and TMV 2, but the total TR value from 5 to 17 days after stress imposition were about 20% higher in TAG 24 than in TMV 2, showing that TAG 44 was able to manage better its water uptake compared to TMV 2, which allowed it to maintain higher NTR later during the stress. At harvest, root depth was measured after washing the roots and stretching. The root were cut in 15 cm portions, which were dried and weighted. We found that there was no significant correlation between either root dry weights, or with root dry weight in each of the 15-cm portion and TR. By contrast, total TR between 5 and 17 days after stress imposition was related to root depth. These data show that there is variation for the pattern of water extraction, and that root dry weight, which is usually well correlated to root length density, appears to be a poor proxy for water uptake.

Vincent Vadez

Milestone: Molecular markers ready for validation and use in introgression studies for abiotic and biotic stresses (VV/RA/SNN/RKV) 2009

The set of polymorphic markers suitable to map QTLs in groundnut is being built up.

Rajeev Varshney and Vincent Vadez

Milestone: QTLs for root traits identified (VV/SNN/RA) 2011

In the experiment reported above, we showed that though root traits displayed variation between genotypes. Only the differences in root depth were related to differences in water uptake, whereas differences in dry weight at different soil depth were not. Furthermore, differences in water extraction in the last 10 days of the experiment were relatively larger than the differences in root depth. This shows that water uptake is probably a better estimator of "root" traits than root traits (such as root length density, depth, dW, etc.) traditionally measured.

Vincent Vadez

Output target 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 6B.2.1: Develop groundnut transgenic events for enhanced tolerance to drought

Milestone: 50 transgenic events of groundnut with DREB1A gene screened for drought tolerance in the contained greenhouse (KKS/VV/RA) 2007

The transcription factor *DREB1A,* which regulates the gene expression via recognition of the DRE (Dehydration Responsive Element) sequence was placed under the control of the stress inducible *rd29A* promoter, both isolated from *Arabidopsis thaliana*, and introduced into the peanut variety, JL 24 through *Agrobacterium tumifaciens* mediated gene transfer. Over 50 transgenic events were produced and advanced to the T_4 generation. The transformants were screened by polymerase chain reaction (PCR), RT-PCR, and Southern analysis for the presence and expression of *DREB1A*. Initial assessment of 14 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). A significant positive correlation with SCMR($r = 0.7359$) and a negative correlation with specific leaf area (SLA) ($r = 0.8237$) were obtained. However, TE did not correlate significantly with $\Delta^{13}C$, thus suggesting a lack of relationship between TE and $\Delta^{13}C$. Two events, RD2 and RD11 appeared to have higher TE than original cultivar JL 24.

Comparison of promising events RD2 and RD with high TE (JUG 24), and low TE (TAG 24) materials: The purpose of this experiment was to confirm the superiority of these events and compare them to known germplasm for high (JUG 24) and low (TAG 24) TE level. JL 24 had TE at the level of TAG 24, which was expected, lower than TE in JUG 24. Results confirm that RD 2 has a higher TE than JL 24 under water deficit conditions. It also showed that RD 2 had higher TE than the best reported genotype (JUG 24) for TE under water deficit. Event RD 11 had a TE that was only slightly above that of JL 24 and TAG 24. Therefore, only RD 2 event appeared to confirm its previous superiority for TE.

Effect of DREB1A on the response to water deficit at different growth stages (early flowering, late-flowering, and pod-filling): This experiment was carried out to: i) measure TE at different stages in two transgenic events (RD 2 and RD 11), control JL 24, and few breeding lines; and ii) test the effect of a water deficit applied at different stages (early flowering, late-flowering, and pod-filling) on pod yield and pod number. We used the standard dry-down technique to apply the stress at different stages. At each stage, TE was measured so that sets of plants were harvested before imposing the stress, and others (well-watered and water stress) harvested after water stressed plants had depleted all the soil moisture. To measure and compare the effect of a drought spell at different stages on the final pod yield, we applied the treatment (WS and WW) to two more sets of plants at each stage. After treatment imposition, the WS were re-watered and kept until maturity along with the WW set. The WS set was re-watered when their relative transpiration was between 10 - 20% of that of control. We based our analysis on pod numbers per plants, rather than pod yield because of mite infection towards the end of crop maturation.

The TE measured at flowering stage was higher in RD 2 and RD 11 than in JL 24 under water stress conditions, but was similar in all the lines under WW conditions. At the late flowering stage, TE of RD was superior to that of JL 24 only under WW conditions, whereas TE of RD 11 was similar to JL 24. Under water stress, TE was similar in all three lines.

The effect of a water stress at mid-pod filling stage had no influence on the pod number relative to the control (pod number was 90% of control across all genotypes), although a few genotypes such as ICR 48 and JUG 26 had a relatively lower pod number under stress. By contrast, the relative pod number of plants exposed to stress at early- and late-flowering was 63 and 76 % of that of the control across all genotypes tested, with a fairly large variation across genotypes (35 - 93% for early-flowering stage, and 49 - 98% for late-flowering stage). During the early-flowering stage, the drought tolerant genotype ICGV 91114 was able to maintain 93% of control pod number. RD 2 and RD 11 maintained 82 and 56% of control pod number, respectively, whereas JL 24 maintained only 63 % of control pod number, indicating that RD 2 was able to maintain pod number when exposed to stress. When the stress was applied at the late-flowering stage, there were no differences in relative pod number between RD 2 and JL 24 (61% in both cases). The breeding lines ICGV 91114, TAG 24, and ICGV 86031 had a relative pod number at about 90% of the control. This experiment showed that flowering is an extremely sensitive stage to water deficit, where the differences between the genotypes were maximum.

Five more transgenic events of groundnut transformed with rd29::DREB1A were tested for TE. The positive plants were tested at T_2 stage. Using the regular dry-down technique, a large number of replicates were tested for each genotype. We included also RD2, the event showing consistently higher TE in previous experiments. Under WW conditions, TE of RD was similar to that of JL 24. However, one event, RD33, had higher TE under WW than JL 24 (7.70 vs 4.80). Under water stress conditions, RD2 had higher TE than JL 24 (7.42 vs 4.89). Two events (RD33 and

RD34) also had TE superior to JL 24. Event RD33 had higher TE than JL 24 across water regimes, and even higher TE than best lines identified so far RD2. We also recorded transpiration response as a function of FTSW (index for soil moisture content) and found that all DREB1A plants showed a decline in transpiration in dryer soil than JL 24. This pattern is fully consistent with previous experiments using DREB1A transformants. A repeat of that experiment is planned to confirm the differences.

The lysimetric system described above has been used to assess 5 DREB1A transgenics (RD2, RD11, RD12, RD19, and RD20) and their non-transformed parent. The experimental design was similar to that described above, except we had 6 replications for each set (pre-treatment harvest at 30 DAS, WW, and WS treatment). Shoot dry weight data are still pending. Normalized transpiration dropped to about 50 - 60% of control at 12 days after stress imposition. Thereafter, NTR of RD 11 was above that of control JL 24. The total transpiration was also greater in several transgenics than in JL 24. For instance, transpiration of RD 19 during the 12 - 42 days after stress imposition was about 600 times higher than that in JL 24 (1788 g vs 2375 g water) under WS conditions. Under WW conditions, RD 19 used about 600 g more water (5933 g vs 5333 g). This showed that under water stress, RD 19 was able to take up relatively more water than JL 24. This trend was true in all transgenic plants. In fact, a remarkable finding of that work was that root dry weight of all 6 genotypes was within a very narrow margin under WW conditions (1.48 – 1.63 g, with JL 24 having 1.61 g). By contrast, under WS conditions, root dry weight of JL 24 remained unchanged (1.73 g) whereas it increased in all transgenics dramatically and reached a range of 2.27 – 2.65 g (30% increase). Under WS conditions, all transgenics had more profuse rooting in deep layers compared to JL 24, whereas under WW, there were no differences. There was a good correlation between the root dry weight within the 40 - 120 cm depth and the total transpiration ($r^2 = 0.41$). It was rather unexpected that DREB1A transgenic could have such a root-related response. This trial has shown the importance of understanding the kinetics of water uptake, more than the importance of knowing about the roots.

Evaluation of transgenic plants in culture chambers: There is a convergence of evidence from the literature and from our own work, in particular in groundnut, that there may be genotypic differences in the sensitivity of stomata to the vapor pressure deficit (VPD). That fact is getting documented in a "slow-wilting" genotype of soybean (PI 416937) that shows no further increase in transpiration at VPD level above 2 kPa, whereas other genotypes of soybean maintain a linear increase in transpiration with VPD level increasing above 2 kPa. Practically, such behavior would shutdown stomata during the hours of the day reaching the highest VPD, trading-off some loss of carbon fixation for water saving, and therefore, contributing to higher transpiration efficiency. Here the purpose of the experiment was to test whether a transgenic line having consistent higher TE than wild type JL 24 differed in stomatal sensitivity to VPD.

The plants were grown in the P2 facilities until about 30 days, and then transferred to growth chamber having different combinations of temperature and humidity, resulting in VPD of 0.63, 1.01, and 1.66 kPa. Plants were left for acclimatizing for 2 days, after which they were submitted to a dry-down experiment. Under WS conditions, there were no differences in TE between JL 24 and RD 2. By contrast, under WW conditions, TE was higher in RD 2 than in JL 24, across the 3 VPD environments.

Several tests to measure response to stepwise increase in VPD were conducted. A ladder of VPD conditions was set up throughout the day, with 60 min for each VPD value. Prior to that, the transpiration was measured gravimetrically from 9.00 am to 16.00 pm (by weighing pots every hour) to check any possibility of a diurnal effect. Data showed that transpiration was virtually constant throughout the day. Therefore, the response of transpiration to stepwise increase in VPD could be assessed without any data adjustment. The first ramp of VPD increases (0.95, 1.13, 1.35, 1.6, 1.88, 2.21, and 2.58 kPa) gave a strict linear increase in transpiration at each VPD interval, with no significant difference between the slopes of the two genotypes. Since plants in the natural environment face higher VPD, a ramp exploring higher values of VPD was also tested (0.95, 1.51, 2.02, 2.31, 2.64, 3.01, and 3.43 kPa). This ramp also gave a linear increase in transpiration in both genotypes, with no significant differences in the slope between the two genotypes. The same ramp carried out 5 days later also gave a linear increase in transpiration, until VPD was 2.31 kPa. At VPD values above 2.31 kPa, there seemed to be no increase in transpiration.

Vincent Vadez and KK Sharma

Progress reported towards the achievement of milestone for 2007 will contribute towards achievement of the milestones listed below.

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

Milestone: Three promising transgenic events of groundnut identified for drought tolerance and characterized under contained field conditions (KKS/VV/RA) 2009

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

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

Activity 6B.2.2: Mapping and marker-assisted breeding for salinity tolerance in groundnut

Milestone: At least 10 genotypes with superior salinity tolerance identified (VV/RA/SNN/RKV) 2007

Screening of 288 groundnut genotypes has been carried out for salinity tolerance. Over 6-fold range of variation for salinity tolerance was observed in this material. High yielding varieties (ICGV 87187, ICGV 86155, ICGV 00309, ICGV 93382, ICGV 97245, ICG 3027, ICG 76, ICG 5195, ICG 6892, and ICG 11651) would be used to screen the molecular diversity and most diverse parental genotype combinations will be used to develop mapping populations. Confirmation of the tolerance is under way.

Vincent Vadez

Milestone: Mapping populations between contrasting parents for salinity tolerance developed to identify QTLs (VV/RA/SNN/RKV) 2008

A set of contrasting parents for salinity tolerance based on the screening for pod yield under salinity has been given to the breeding group. Contrasting parents will be also assessed for their level of polymorphism, using a number of SSR markers. After confirmation of the contrast in salinity tolerance between the parents, and after ensuring that parents have sufficient level of polymorphism at the DNA level, the F_2 populations will be advanced by single-seed descent.

Vincent Vadez and R Aruna

Milestones: QTLs for salinity tolerance identified (VV/SNN/RA) 2011

Tolerant and sensitive groundnut genotypes for salinity tolerance have been dentified and crosses are currently being made.

V Vadez, SN Nigam and Aruna R

Output B. Annually 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

Chickpea

MTP Output Target 200: New Kabuli and desi germplasm with early maturity to avoid drought developed and made available to partners

Output target 6B.1: Identification of QTLs for drought avoidance root traits and salinity tolerance in chickpea

Activity 6B.1.1: Mapping and marker-assisted breeding for drought tolerance in chickpea

Milestones: Molecular markers for additional QTLs for drought avoidance root traits identified (PMG/JK/LK/RKV) 2007

Evaluation of new RIL populations for phenology, yield, and yield contributing traits: Two new RIL populations (ICC 283 x ICC 8261 and ICC 4958 x ICC 1882) developed for mapping of additional QTLs for drought avoidance root traits were evaluated for phenology, yield, and yield traits. A total of 281 F_8 RILs of ICC 283 x ICC 8261 and 264 F_8 RILs of ICC 4958 x ICC 1882 were evaluated in an augmented design along with the parental lines. Both populations exhibited a wide range of variability for all traits studied (Table 3). Over 120 RILs of ICC 283 x ICC 8261 gave 10 to 96% higher yield than the drought tolerant parent ICC 8261, while 25 RILs of ICC 4958 x ICC 1882 gave 10 to 26% higher yield than the higher yielding drought tolerant parent ICC 4958. A RIL population of ICC 4958 x ICC 1882 has been phenotyped using tall cylinder (120cm height) culture systems in 3 replications in 2005 post-rainy season. The substantial variation was observed in root length density, rot dry weight and rooting depth between the parental lines, and the RILs showed normal distribution on these root traits. In ICC 283 x ICC 8231, the phenotyping has been completed in 2006 post-rainy season, and analysis is going on. These populations are being phenotyped for root traits and genotyped using polymorphic SSR markers.

Table 3. Variability for different traits in two new RIL mapping populations developed for mapping of drought avoidance root QTLs.

	ICC 283 x ICC 8261 RIL population			ICC 4958 x ICC 1882 RIL population		
	ICC 283	ICC 8261	ICC 283 x ICC 8261 RILs	ICC 4958	ICC 1882	ICC 4958 x ICC 1882 RILs
Days to 50% flowering	60	58	45-88	50	54	42-66
Days to maturity	125	126	108-140	116	110	105-119
Plant height (cm)	35.0	56.0	30.0-64.0	43.7	39.3	26.0-56.3
Plant width (cm)	12.7	18.3	9.0-53.7	18.0	26.7	13.3-44.3
No, of primary branches per plant	2.7	3.3	1.7-6.7	2.3	3.0	1.3-4.3
No. of secondary branches per plant	2.0	3.0	1.0-11.7	3.0	4.7	1.3-6.3
No. of pods per plant	92	37	24-220	41	135	26-238
100-seed weight (g)	16.2	32.2	10.3-33.1	39.4	13.7	13.4-35.3
Biomass (kg ha^{-1})	1996	3013	1146-4413	3158	2650	479-4443
Seed yield (kg ha^{-1})	1036	1095	356-2148	1820	1453	270-2476
Harvest index (%)	51.9	36.3	24.6-60.0	57.6	54.8	24.6-66.2

PM Gaur and J Kashiwagi

Milestones: QTLs for drought avoidance root traits validated (PMG/JK/LK/RKV) 2009

This milestone is linked to the progress reported above, and one population will be used for mapping, and another for validation of QTLs.

Milestones: MABC-derived drought tolerant lines available from 2-3 locally adapted cultivars (PMG/JK/LK/RKV) 2011

Initiation of MABC for introgression of drought avoidance root traits in farmer-preferred cultivars: We identified three farmer-preferred cultivars, JG 11 in Desi type and Chefe (ICCV 92318) and KAK 2 (ICCV 92311) in Kabuli type for introgression of large root traits (high root length and high root depth density) from ICC 8261 (Kabuli) and ICC 4958 (Desi) using marker-assisted backcrossing (MABC). Six crosses (JG 11 X ICC 8261, KAK 2 X ICC 8261, Chefe X ICC 8261, JG 11 X ICC 4958, KAK 2 X ICC 4958, Chefe X ICC 4958) were made during 2006 in the greenhouse. The F_1s from these crosses are being grown during the post-rainy season 2006/07 along with parents for making backcrosses with the parental cultivars.

PM Gaur, J Kashiwagi and Rajeev Varshney

Activity 6B.1.2: Mapping and marker-assisted breeding for salinity tolerance in chickpea

Milestones: Phenotyping of ICCV 2 x JG 62 mapping population for salinity tolerance completed and data analyzed with available data for QTL mapping (VV/LK/RKV/PMG) 2007

The phenotyping of 125 F_{13} progenies from ICCV 2 x JG 62 cross has been completed under controlled saline conditions (saline treatment corresponding to an application of 1.870 L of a 80 mM NaCl solution to 7.5 kg of black soil from ICRISAT farm). The seed yield under salinity ranged from 4.05 g pot^{-1} to 14.5 g pot^{-1} in the 126 RILs, showing a 3-fold range of variation, and there was a very good segregation pattern. Parents ICCV2 (sensitive) and JG62 (tolerant) were at the extremes of the ranking, with seed yield being 7.77 g pot^{-1} (23rd from bottom) and 13.46 g pot^{-1} (6th ranked among all), respectively. QTL analysis is yet to be performed.

Milestone: Mechanisms of tolerance to salinity characterized (VV/LK/NM) 2008

Screening of 263 accessions of chickpea, including 211 accessions from ICRISAT's mini-core collection (10% of the core collection, and 1% of the entire collection), showed a six-fold range of variation for seed yield under salinity, with several genotypes yielding 20% more than the previously released salinity tolerant cultivar. The range of variation in yield under salinity was similar in both Kabuli and Desi chickpeas, indicating that breeding for salinity tolerance can be undertaken in both groups. A strong relationship was found between the seed yield under salinity and the seed yield under a non-saline control treatment, indicating that the seed yield under salinity was explained in part by a yield potential component, and in part by salinity tolerance *per se*. Seed yields under salinity were therefore computed to separate the yield potential component from the residuals that accounted for salinity tolerance *per se*. Among the genotypes evaluated, Desi genotypes showed greater salinity tolerance than the Kabuli genotypes. The residuals were highly correlated to the ratio of seed yield under salinity to that of the control, indicating that both parameters can be used to assess salinity tolerance. A similar ratio was calculated for shoot dry weight at 50 days after sowing. However, no significant correlation was found between the shoot dry weight ratio and the grain yield ratio, indicating that differences in salinity tolerance among genotypes could not be inferred from measurements at the vegetative stage. The major trait related to salinity tolerance was the ability to maintain a large number of filled pods, whereas seed size was similar in tolerant and sensitive genotypes. Salinity tolerance was also not related to the Na^+ or K^+ concentrations in the shoot.

Vincent Vadez and L Krishnamurthy

Milestone: New RILs populations for mapping of salinity tolerance QTLs developed (PMG/VV/LK) 2009

A set of 10 tolerant and 10 susceptible lines with salinity tolerance have been provided to the chickpea breeding group. Three crosses have been developed: ICC 6263 (DF 70) x ICC 1431 (DF 69), ICC 15802 (DF 66) x ICC 9942 (DF 63), and ICCV 2 (DF 39) x JG 11 (DF 40). These genotypes will also be assessed for their range of polymorphism at the DNA level, using a set of SSR markers.

PM Gaur, Vincent Vadez and L Krishnamurthy

Milestone: QTLs for salinity tolerance identified (VV/LK/RKV/PMG) 2009

The phenotyping of 125 F_{13} progenies from ICCV 2 x JG 62 cross has been completed under controlled saline conditions (saline treatment corresponding to an application of 1.870 L of a 80 mM NaCl solution to 7.5 kg of black soil from ICRISAT farm). Grain yield has been recorded at maturity. The seed yield under salinity ranged from 4.05 g pot^{-1} to 14.5 g pot^{-1} in the 126 RILs, showing a 3-fold range of variation, and there was a very good segregation pattern. Parents ICCV2 (sensitive) and JG62 (tolerant) were at the extremes of the ranking, with seed yield being 7.77 g pot^{-1} (23rd from bottom) and 13.46 g pot^{-1} (6th ranked among all), respectively. QTL analysis is yet to be performed.

Vincent Vadez and L Krishnamurthy

Milestone: QTLs for salinity tolerance introgressed in farmer-preferred varieties (PMG/VV/LK/RKV) 2011

The work on this milestone will start when RIL populations are available from the above milestone in 2009.

Output target 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 6B.2.1: Develop and evaluate chickpea transgenic events for enhanced tolerance to drought stress

Milestones: 50 transgenic events of chickpea with DREB1A and P5CSF genes developed and screened for drought tolerance in the contained greenhouse (KKS/VV/PMG) 2007

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 advanced to T_4 generation to maintain the homozygosity. 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. Inheritance studies carried out on the T_3 generation transgenic plants showed a 15: 1 segregation for both types.

Ten transgenic events each of rd29A:DREB1A and 35S: P5CSF129A in T_3 generation were evaluated in drydown experiments to study various physiological parameters including plant response to soil drying as measured by the fraction of transpirable soil water (FTSW), stomatal conductance, and transpiration efficiency (TE). The events exhibiting a diversity of stress response patterns, especially with respect to the NTR-FTSW relationship were selected from that ranking and comparative studies were carried out with these transgenics under optimized conditions for evaluating the water use efficiency of the selected events. All the selected transgenic events differed from the wild type parent in their NTR response to FTSW, showing a decline in transpiration at lower FTSW values (dryer soil). Several events had superior transpiration efficiency, photosynthetic activity, stomatal conductance, and total transpiration under water limited conditions in comparison to the control parent C 235. All the selected transgenic events had a transpiration decline in drier soil than in the untransformed parent. The total biomass produced during the dry down cycle (Δ biomass) showed differences amongst the transgenic events, thus indicating apparent differences in the biomass produced per unit of water used.

A repeat experiment was performed with 5 transgenic events of DREB1A and 4 events of P5CSF. We measured the response of transpiration to progressive drying and also measured TE using standard protocol. Among the different events tested, one DREB1A event (RD 2) had higher TE than wild type C 235 under water deficit. This event was also among the few having higher TE than control variety C 235 in the previous experiment, which confirms its superiority. One event of P5CSF (P8) also showed superior TE than control C 235, whereas TE in the other 3 events was similar or below C 235.

Vincent Vadez and KK Sharma

Progress reported towards the achievement of milestone for 2007 will contribute towards achievement of the milestones listed below.

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

Pigeonpea

Output B. Annually 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

MTP Output Target 2006: New germplasm with early maturity to avoid drought developed and made available to partners

We have made use of drought avoidance traits like earliness and high root volume for breeding lines suitable for drought prone areas. We have field tested a few promising extra short duration lines such as ICPL 88039, MN 5, MN 8 and ICPL 88039 in the drought prone conditions of Rajasthan, India. The variety ICPL 88039 was found superior in terms of yield (over 21%) and earliness (about two weeks) over the popular check 'Manak'. To follow up we have multiplied breeder's seed of ICPL 88039, MN 5 and MN 8 for distribution to the NARS partners, and for testing in their locations under local practices.

The recently developed photo-insensitive extra-early (90 days) breeding lines have permitted pigeonpea cultivation in new niches at higher latitudes and altitudes. Some seed of this line (ICPL 88039) have been dispatched to partners. This line is already showing impact because it has led to the diversification of the rice-wheat system in north India with about 0.2 million ha additional pigeonpea area being grown. Since the available short-duration varieties are susceptible to diseases like sterility mosaic (SMD), lines have been developed that combine early maturity and SMD resistance, in particular ICP11632, ICP 11719, ICP 16665, ICP16166, ICP16169, ICP16293, ICP14399. The early maturity of these lines would confer on them a useful drought escape mechanism. A large number of trials have been performed in farmer's field to test for SMD resistance in early maturing lines.

In term of seed production and distribution of early maturing materials, 795kg of ICPL 88039, 25kg of ICPL 87 and 25 kg of ICPL 87091 have been produced to cater for national and international demand for seeds of early maturity types. A recent extra effort in the area of pigeonpea production has been made in the Philippines where the early maturity line ICPL 88039 has been sent for preliminary testing.

KB Saxena

Output target 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 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

Identify superior pigeonpea genotypes for salinity tolerance: We assessed the morphological and physiological variation in pigeonpea for salinity tolerance in 300 genotypes, including the minicore collection of pigeonpea, wild accessions, and landraces from putatively saline prone areas worldwide. There was 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^{+} accumulation in shoot showed that more tolerant cultivated materials accumulated less Na in shoot. Such relationship was not true for the wild species. Wild species such as *C. acutifolius, C. cajanifolius,* and *C. lineata* were highly sensitive, whereas *C. platycarpus, C. scarabaeoides,* and *C. sericeus* were tolerant. It was interesting to note that *C. scarabaeoides* also provided a large range of sensitive materials. The minicore 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. Data were published in the 2nd issue of the electronic Journal of the Semi Arid Tropic Agriculture Research, and is available online at: www.icrisat.org. The methods and traits used to assess salinity tolerance in groundnut and pigeonpea have been put together in a paper submitted to the Indian Journal of Crop Science.

Vincent Vadez and KB Saxena

Activity 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

Cajanus platycarpus, C. scarabaeoides, and *C. sericeus* were found to be tolerant and will be used for development of mapping populations. The minicore collection of pigeonpea provided a large range of variation for salinity tolerance. Contrasting parents in minicore would also be available for crossing and development of mapping populations.

Vincent Vadez and KB Saxena

Milestones: QTLs for salinity tolerance identified in pigeonpea (VV/KBS) 2011

The screening of breeding lines has revealed a large range of variation for salinity tolerance, both in the wild and the cultivated pigeonpea. Given the low level of polymorphism within cultivated pigeonpea, accessions are available to develop both intra- and inter-specific RIL populations.

Vincent Vadez and KB Saxena

Output C: Annually knowledge of the improvements of the biotechnological and conventional tools designed to facilitate bio-fortification and bio-detoxification, breeding improved germplasm, and management strategies of mandate crops and associated capacity building made available to partners internationally

MTP Output Target 2006: Variability of Fe and Zn in 80 germplasm lines developed and quantified in sorghum

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 6C1.1: Develop groundnut transgenic events for enhanced production of beta-carotene

Milestone: 75 transgenic events of groundnut with maize psy1 gene developed and screened for high ß-carotene production in the contained greenhouse (KKS/SNN) 2007

Development of groundnut transgenics for enhanced β-carotene: Binary gene constructs harboring the ß-carotene biosynthetic genes, phytoene synthases (*psy*1 and *crt*B) from maize and *Erwinia herbicola,* respectively, were developed. These genes are driven by oleosin promoter for oil body seed specific expression, and are being used in *Agrobacterium*-mediated genetic transformation for the enhancement of ß-carotene in groundnut seeds. Over 70 putative transgenic groundnut plants were transferred to the containment greenhouse for seed development. The T_0 putative transgenic plants were analyzed for the integration of transgenes by using PCR with gene-specific primers, and Southern hybridization, with gene specific probes. In molecular analysis, 70% of putative groundnut transgenic plants showed the integration of *psy*1 gene. The transgene expressions were observed in the developing pods of groundnut by RT- PCR analysis. The presence of mRNA transcripts of *psy*1 gene was found in 3 out 4 plants tested. The T_1 seeds from transgenic events of PSY1 are being collected for further generations to study gene stability, inheritance, and expression of transgene. The procedure for beta-carotene extraction and analysis in groundnut seeds was optimized. The quantification of beta-carotene in primary transgenic groundnut seeds is in progress for the selection of best events. In a preliminary analysis, the enhancement of ß-carotene was observed in 2 out of 10 events tested that showed the levels of 10 $\mu g\ g^{-1}$ of the seed. For the development of marker-free transgenic plants, maize *psy*1 gene driven by oleosin promoter was sub-cloned into binary vectors pCAMBIA 2300:φ*npt*II (minus kanamycin gene). Around 30 marker-free putative groundnut transgenic plants carrying the m*psy*1 genes were transferred to the containment greenhouse. Molecular analysis is being carried out for these transgenic plants. Similarly, for the development of antibodies against phytoene synthase, the *psy*1 gene was cloned into pET expression vector. The over expression of PSY1 protein in *E. coli* is being analyzed.

A Vanamala, KK Sharma and SN Nigam

Progress reported towards the achievement of milestone for 2007 will contribute towards achievement of the milestones listed below.

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

Milestone: Three promising transgenic events of groundnut identified for high ß-carotene production and characterized under contained field conditions (KKS/SNN) 2009

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

Milestone: 5 - 7 introgressed transgenic lines of groundnut with improved beta-carotene content evaluated and development of commercialization package initiated (KKS/SNN/RA) 2011

Activity 6C1.2: Develop pigeonpea transgenic events for enhanced production of beta-carotene

Milestone: 50 transgenic events of pigeonpea with maize psy1 gene developed and screened for high ß-carotene production in the contained greenhouse (KKS/KBS/KML) 2007

Development of pigeonpea transgenic events for enhanced level of ß-carotene: *Agrobacterium*-mediated genetic transformation is being carried out regularly using the binary vectors containing maize *psy*1 gene driven by oleosin promoter for generating pigeonpea transgenic events with enhanced level of ß-carotene. The putative transgenic pigeonpea shoots obtained under antibiotic selection pressure are being elongated for rooting. About 40 putative transgenic plants with maize *psy*1 have been transferred to the containment greenhouse for further analysis. The primers specific to the coding sequence of *psy*1 genes were designed and conditions for PCR amplification were optimized. The primary T_0 putative pigeonpea plants are being molecularly analyzed using PCR for the presence of *psy*1 gene.

Development of pigeonpea transgenic events for enhanced level of methionine: In separate studies, binary gene constructs containing *SSA* gene driven by vicillin promoter (pHS723:SSA) in *Agrobacterium tumefaciens* strain C 58 is being used for the development of pigeonpea transgenics for enhanced level of seed methionine content. Around 20 putative transgenic plants were transferred to the containment greenhouse for further analysis. The primers specific to the coding sequence of *SSA* genes were designed and conditions for PCR amplification were optimized. The primary putative transgenic pigeonpea plants obtained under antibiotic selection pressure are being analyzed using PCR for the presence of *SSA* gene.

A Vanamala, KK Sharma and KB Saxena

Progress reported towards the achievement of milestone for 2007 will contribute towards achievement of the milestones listed below.

Milestone: At least 8 promising transgenic events of pigeonpea containing maize psy1 gene identified and their stability characterized under contained greenhouse conditions (KKS/KBS/KML) 2008

Milestone: Three promising transgenic events of pigeonpea identified for high ß-carotene production and characterized under contained field conditions (KKS/KBS/KML) 2009

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/KML) 2010

Milestone: 5 - 7 introgressed transgenic lines of pigeonpea with enhanced beta-carotene content evaluated and development of commercialization package initiated (KKS/KML) 2011

MTP Output Target 2006: 10 new groundnut varieties with resistance to aflatoxin contamination made available to partners

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 plants 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/PLK/SNN) 2007

Aspergillus flavus and *A. parasiticus*, with the ability to produce aflatoxins in groundnut, present a great human and animal health hazard globally. Extensive efforts for developing resistance to *A. flavus/A. parasiticus* infection and aflatoxin contamination in cultivated groundnut have resulted in the identification of partially resistant genotypes. Genetic engineering approach was therefore initiated to develop groundnut germplasm with durable resistance to *A. 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. Thirty transgenic events were selected that were positive for the *RChi* gene integration. These events were assessed for resistance against *A. flavus* seed colonization by *in vitro* seed inoculation with *A. flavus* spores. Fifteen *RChit* transgenic events that showed promising resistance during T_2 generation were evaluated for post-harvest seed resistance to *A. flavus* by *in vitro* seed inoculation assay by blotter plate method. Seeds (10 - 15% moisture) were surface sterilized with 0.1% (v/v) mercuric chloride and inoculated with *A. flavus* (strain AF 11-4) spore suspension (1×10^6 spores ml^{-1}) and placed on a moist blotter paper in a petridish, and incubated in a humid chamber maintained at 80% relative humidity and 28°C for six days. The percent seed infection was recorded at the end of 6th day. Seeds of progenies with less than 10% infection were advanced to next generation by planting uninfected seed only. This procedure was continued up to T_5 generation. Post-harvest infection in the transgenic groundnut seed ranged between 0 to 100%, compared to 60 to 100% in controls. A few progenies of nine events numbers 12, 23, 24, 27, 29, 30, 31, 36, and 44 showed consistently low seed infection (<10%). Although progenies with less than 10% seed infection were advanced, seed from subsequent generation had infection between 0 to 100%. This variability could be due to the levels of *Rchit* expression and seed moisture at the time of infection. Seed from T_5 progenies of the nine selected events were bulked and these will be evaluated in an *A. flavus* sick plot in a contained on-station trial in 2007.

To assess resistance to *A. flavus* in germinating seed, three transgenic events (# 12, 23, and 24) and control (JL 24) seeds were pre-soaked for 24 h and 48 h in moist petridishes, and then inoculated with *A. flavus* spores. Observations were recorded after 6 days of inoculation. Infection in germinating seed was lower than un-germinated transgenic seed and controls. However, low-seed infection was also observed in germinating control seed, which may be due to the activation of native seed defense mechanism. Overall, the percent seed infection in germinating transgenic seed was always lower than germinating control seed, indicating likely action of *Rchit* gene product and native seed defense contributing to high resistance.

Further work is in progress to understand the gene expression, *Rchit* accumulation in seed, and *Rchit* activity in the seed at various moisture levels and its effect on *A. flavus* inhibition. The transgenic events will be evaluated for pre-harvest *A. flavus* infection following the regulatory approval for on-farm trials in the sick plot established at ICRISAT-Patancheru farm.

KK Sharma, Lava Kumar and Farid Waliyar

Progress reported towards the achievement of milestone for 2007 will contribute towards achievement of the milestones listed below.

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

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

Milestone: Five promising transgenic groundnut events with PNLOX13S identified and disease resistance characterized under contained field conditions (KKS/FW/PLK/SNN) 2010

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

Output target 6C.3: Simple and cost-effect test for the estimation of mycotoxins (Aflatoxins, Fumonisins, and Ochratoxin-A) in crops and commodities, and aflatoxin-adducts in human serum developed and validated

Activity 6C.3.1: Develop a diagnostic test to determine the human exposure to aflatoxins

Milestone: Enzyme-linked immunosorbent assay (ELISA) assay developed for the estimation of aflatoxin adducts in human serum (FW/PLK) 2007

Development of ELISA for determining human exposure to aflatoxins: Aflatoxins are naturally produced food-borne metabolites of *Aspergillus flavus* and related fungi found in most of the food crops grown in tropics and sub-tropics. Aflatoxins constitute a group of four compounds, aflatoxin B1 (AfB1), B2, G1, and G2. Severe intoxication due to consumption of highly contaminated food results in acute liver damage and even death. Frequent exposure to sub-lethal doses leads to several nutritional and immunological consequences and greatly increases the risk of liver cancer. Moreover, research during the past two decades has established a synergistic interaction between Hepatitis B virus infection and AfB1 in causing liver cancer. Various studies suggest that the chronic type of aflatoxin poisoning is common in many parts of developing countries in Asia and Africa, and usually goes unnoticed. In order to assess the risk of human exposure to aflatoxins, a simple competitive enzyme-linked immunosorbent assay (ELISA) was developed. This test is based on the estimation of AfB_1-lysine, a metabolite of AB1, whose concentration in the blood albumin fraction has been shown to correlate with dietary aflatoxin intake over the previous 2 - 3 months and the level of DNA damage in the liver. The test involves isolation of the albumin fraction from blood, followed by digestion of albumin and estimation of AfB_1-lysine content by ELISA using AfB1-lysine polyclonal antibodies produced at ICRISAT. These polyclonal antibodies were raised against AFB1-lys-BSA adducts in a New Zealand White rabbit. In the ELISA test, polyclonal antibodies are first bound to the AfB_1-lysine present in the extracted albumin. Then, the antibody- AfB_1-lysine complex is detected using an alkaline phosphatase enzyme-labeled reporter antibody. Finally, the enzyme-labeled reporter antibody is detected using a colorimetric reaction that provides an estimate of the original AfB_1-lysine concentration. The current test can detect levels of AfB_1-lysine in blood as low as 5picogram per milligram (pg mg^{-1}) albumin. The test is simple to perform, inexpensive, and is effective for routine monitoring of human as well as animal samples for aflatoxin exposure.

The assay was used in a survey of 80 HBV positive blood samples from the Hyderabad region in India. The results revealed that almost 20% of the samples contained AfB_1-lysine in the range of 5 - 30 picogram mg^{-1} albumin, indicating that there is a high risk for liver cancer in Hepatitis B positive individuals. This simple test can be used to screen large numbers of samples and provides scope for preventive interventions in individuals at high risk of liver cancer. This test compliments commercial HBV testing, and the ELISA test we developed earlier for the detection of aflatoxins in foodstuffs. Both tests allow field studies to identify aflatoxin-exposed populations, determine the source of contaminated food, and initiate management approaches to limit dietary-aflatoxin exposure, thereby enhancing the food and human health safety and reducing the risk of hepatocellular carcinoma.
Lava Kumar/Farid Waliyar/CN Reddy

Activity 6C.3.2: Develop simple and cost-effective assays for the detection of mycotoxins in crops and commodities

Milestones: Simplified ELISA-based assay for the detection of mycotoxins developed (FW/PLK) 2007

Detection of food-borne mycotoxin contaminants is essential to ensure food safety. A simple and cost-effective competitive ELISA technique has been developed at ICRISAT for the detection of aflatoxins (AfB1, AfB2, AfM1, and total toxins), ochratoxin A ,and fumonisins; which are being widely used. However, these laboratory-based techniques require skilled technicians, and samples need to be sent to the laboratory for testing purpose. However, simple on-site mycotoxin detection methods would aid in testing large numbers of samples by non-experienced technicians in the fields, and rapid identification of contaminated lots, which can be segregated and sent for laboratory analysis for quantitative estimation of mycotoxins. For this purpose, we plan to develop plate-based, tube-based, or filter paper-based (lateral-flow) assays that are suitable for on-site testing. Diagnostic reagents (poly- and monoclonal antibodies, mycotoxin standards, and enzyme conjugates) already developed for the mycotoxin detection at ICRISAT will be used for the development of these tests. To achieve this objective, a simple ELISA method is being developed to distinguish the variable concentration of aflatoxins (0, 2, 5, 10, and 25 ng ml^{-1}) in the samples based on color intensity (chromogenic reaction). ELISA plates were coated with 75 ng ml^{-1} of AFB1-BSA and the AFB1 standard was added at 2, 5, 10, and 25 ng ml^{-1}, and the anti-aflatoxin rabbit antisera was added at 1: 25 K and 1: 50 K, and the alkalinephosphatase enzyme-conjugated anti-rabbit antibody was used at 1:4 000 and the p-nitrophenylphosphate substrate was used at 0.5 mg ml^{-1}. Based on the color intensity in the wells of ELISA plate, samples with more than 5 ng ml^{-1} toxin can be distinguished in 30 min. This qualitative ELISA test will aid in rapid screening of samples to identify lots with more than 5 ng ml^{-1} toxin**.** This procedure is being refined further to develop tube-based and filter paper-based assays.

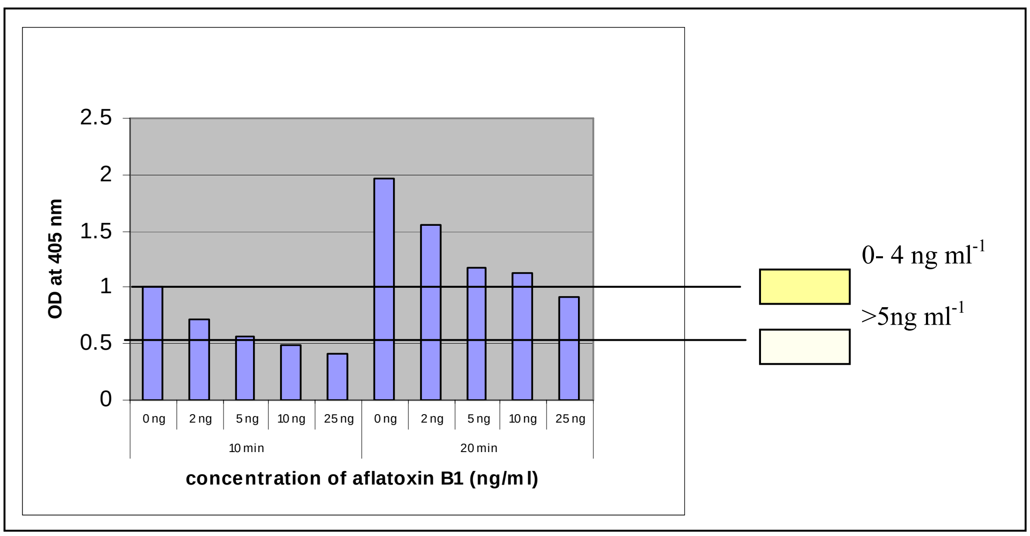


Fig. 1. Differentiation of aflatoxin contaminated lots based on color intensity in ELISA plate

Progress reported for 2007 for this activity will contribute to the milestones listed below.

Milestones: Tube/filter paper based semi-quantitative immuno assay developed for the on-site detection of aflatoxins (FW/PLK) 2008

Milestones: Multiplex filter paper immuno assay developed for the rapid estimation of aflatoxins and fumonisins (FW/PLK) 2009

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: At least 10 - 15 crosses involving diverse germplasm and breeding lines for aflatoxin resistant traits effected (SNN/RA/FW/PLK) Annual

Fifteen new crosses were made in the 2005/2006 post-rainy and the 2006 rainy seasons to develop aflatoxin tolerant breeding lines. The new germplasm lines used in the crossing are ICG 1859, ICG 1326, ICG 3267, ICG 10097, and ICG 3241.

SN Nigam and R Aruna

Milestone: 10 - 15 new high yielding, aflatoxin resistant lines identified and made available to NARS (RA/SNN/FW/PLK) Annual

We evaluated 349 advanced breeding lines (including controls) in 12 replicated trials, and 308 advanced breeding lines in 3 augmented trials for agronomic performance in the 2005/06 post-rainy and the 2006 rainy seasons under normal conditions. All the entries in replicated trials were also grown in an *A. flavus* sick plot to record observations on seed infection by *A. flavus* and aflatoxin production.

2005/2006 post-rainy season: In elite and advanced (Spanish) trials, none of the entries produced significantly higher pod yield than the highest yielding controls. In the elite trial (Virginia type), ICGV 01001 (2.5 t ha^{-1} pod yield, 0.3 % *A. flavus* seed infection, and 0.0 µg kg^{-1} aflatoxin production), ICGV 01002 (2.8 t ha^{-1}, 0.0 %, and 1.1 µg kg^{-1}), ICGV 01120 (3.2 t ha^{-1}, 0.3 %, and 0.0 µg kg^{-1}), and ICGV 02191 (3.0 t ha^{-1}, 0.0 %, and 0.0 µg kg^{-1}) were resistant to infection by *A. flavus* and aflatoxin contamination compared to the resistant control J 11 (2.9 ± 0.13 t ha^{-1}, 0.8 %, and 1.1 µg kg^{-1}). In another advanced trial (Spanish), ICGV 03301 (2.9 t ha^{-1}, 6.3 %, and 1.2 µg kg^{-1}) and ICGV 03328 (2.8 t ha^{-1}, 4.8 %, and 0.5 µg kg^{-1}) were more resistant than the resistant control J 11 (2.4 ± 0.13 t ha^{-1}, 2.5 %, and 222 µg kg^{-1}). In advanced trial involving Virginia types, the performance of ICGV 03363, ICGV 03372, and ICGV 03373 for pod yield and % infection by *A. flavus* (4.7 t ha^{-1}, 0.3 %, and 733.5 µg kg^{-1}; 4.4 t ha^{-1}, 3.0 %, and 21.3 µg kg^{-1}; and 4.9 t ha^{-1}, 0.8 %, and 148.0 µg kg^{-1}) was superior to both resistant J 11 (3.9 ± 0.13 t ha^{-1}, 1.8 %, and 4.3 µg kg^{-1}) and susceptible control, JL 24 (3.7 ± 0.13 t ha^{-1}, 1.0 %, and 5.2 µg kg^{-1}). However, none of these entries were significantly superior to the highest yielding control ICGS 76 (4.3 ± 0.13 t ha^{-1}, 1.8 %, and 9.7 µg kg^{-1}) for pod yield. In a preliminary aflatoxin trial, five lines (4.0 - 4.7 ± 0.68 t ha^{-1}) out-yielded the highest-yielding control ICGS 11 (3.1 t ha^{-1}). In augmented trial-1, ICGX 000109 (adjusted pod yield 4.9 t ha^{-1}) gave significantly higher yield than the highest yielding control ICGS 76 (4.9 t ha^{-1}). In augmented trial - 3, ICGX 000021 (5.2 t ha^{-1}) significantly out-yielded the highest yielding control ICGS 76 (5.0 t ha^{-1}).

2006 rainy season: None of the entries significantly out-yielded the best control in the elite trials (Spanish and Virginia). In the advanced trial - Spanish types, ICGV 04044 (3.9 t ha^{-1} pod yield, 64% shelling outturn, and 51 g 100-seed weight) and ICGV 04040 (3.9 t ha^{-1}, 65%, and 38 g) gave significantly higher pod yield than the highest yielding and resistant control ICGS 11 (2.3 t ha^{-1}, 66%, and 35 g). The best entry, ICGV 04044 came from (ICGV 97077 x ICGV 91284) cross. In the advanced trial - Virginia types, ICGV 06348, ICGV 06344, and ICGV 06345 (3.6 - 3.3 ± 0.33 t ha^{-1}) significantly out-yielded the highest yielding control ICGS 11 (2.3 t ha^{-1}, 60%, and 31 g). The best entry ICGV 06348 came from (ICGV 98077 x ICGV 91284) cross. In the Augmented trial, three entries significantly out yielded (adjusted pod yield 3.8 - 3.2 t ha^{-1}) the best check ICGS 76 (3.1 t ha^{-1}). The best entry in the trial was ICGVX 000109 (3.8 t ha^{-1}). Results of pre-harvest aflatoxin contamination and aflatoxin content are awaited. Six aflatoxin tolerant high yielding lines (ICGV 01060, ICGV 01094, ICGV 02171, ICGV 02184, 02206, and ICGV 02207) were identified during the 2005/2006 post-rainy season for inclusion in international trials.
SN Nigam/R Aruna

Milestone: Preliminary, advanced and elite foliar disease resistant breeding lines evaluated for resistance A. flavus and aflatoxin production under artificial inoculation conditions in the field and at least 5 resistant varieties identified for commercialization (FW/SNN/PLK/RA) 2009

Milestone: Ten interspecific derivatives of groundnut evaluated for A. flavus and aflatoxin resistance and promising lines identified (FW/NM/PLK) 2010

Sixty lines of advanced generation interspecific derivatives of groundnut generated using *Arachis duranensis*, *A. cardenasii* and *A. batizocoi* are being screened for *Aspergillus flavus* colonization and aflatoxin production. The results of the screening experiments are awaited.

Nalini Mallikarjuna

Milestone: Multilocational trials of five A. flavus resistant/low aflatoxin producing interspecific derivatives conducted in target locations in India (FW/NM/RA/PLK) 2012

Activity 6C.4.2: Evaluate various soil amendments and biocontrol agents for reducing pre-harvest *A. flavus*/ aflatoxin contamination in groundnut

Milestones: Efficacy of pseudomonas and actinomycets in preventing pre-harvest aflatoxin contamination determined (FW) 2008

Milestones: Integrated management package using various soil amendments and biocontrol agents, for preventing pre-harvest aflatoxin contamination developed (FW) 2009

Output targets 6C.5: Effective and eco- friendly IPM technologies designed, evaluated , and shared for the management of insect pests in legumes

Activity 6C.5.1: Impact of the village level bio-pesticide production on the effective implementation of IPM

Milestone: Impact of village level bio-pesticide production and utilization documented (GVRR) 2007

Production and utilization of HaNPV at village level: During 2006, emphasis was placed on establishing bio-pesticide units and imparting training on HaNPV production to farmers and extension officers. In this process, 27 HaNPV production units in India and 10 in Nepal have been established after extensive training of farmers and extension staff from each location. Through these interactions (on site training and village wide interactions), this project has influenced the farmers in judicious use of pesticides in plant protection, and the importance of use of protective clothing while carrying out the spraying. Farmers in these villages have adopted the concept of integrated pest management (IPM) and initiated the bio-pesticide production (range 1000 - 10,000 LE among the units), and using the product on different crops (chickpea, cotton, and vegetables) covering an area of about 10 – 50 ha under each unit.

GV Ranga Rao

Milestone: Rural stakeholders trained in biopesticide production and utilization and relevant rural enterprise initiated (OPR) 2009

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

Evaluation of botanicals with insecticidal properties: Eleven indigenous plant materials (*Cleistanthus collinus*, *Calotropis gigantea*, *Pongamia glabra*, *Artemisia dubia*, *Sphaeranthus indicus*, *Cassia occidentalis*, *Chloroxylon swietensia*, *Vitex negundo*, *Madhuca indica*, *Strychnos nuxvomica*, and *Strychnos pototorum*) known for insecticidal properties, were collected from Andhra Pradesh and Chhattisgarh (India),and evaluated against tobacco caterpillar, *Spodoptera litura* larvae. The water extracts of these products tested against second/fourth instar larvae clearly indicated the superiority of *Cleistanthus collinus*, *Calotropis gigantia* (leaf extracts), and *Pongamia glabra* (seed extract) in suppressing the growth and development of *S. litura.* Though none of these plant extracts showed larval mortality, significant reduction in larval growth rate was observed, indicating the antifeedant/antibiotic properties of the extracts. Among the 11 plant materials tested, *Cleistanthus collinus*, *Pongamia glabra,* and *Calotropis gigantia* resulted in slower growth rates of 1.78, 1.96, and 2.07, respectively, compared to 2.74 in untreated control. This resulted in a reduction of 35, 28, and 24% in larval growth rate in comparison to the untreated larvae. Further studies will be carried out to make use of these products in future IPM programs.

GV Ranga Rao

Milestone: Botanicals with ability to kill insects having compatibility with entomopathogenic microorganisms identified and appropriate delivery systems developed (OPR/GVRR) 2008

Characterization of bacterial isolates for multiple traits: Ensuring a healthy crop is a first step towards protecting it from insect pests and diseases. Microorganisms can play a vital role in promoting plant growth, managing insect-pests, and maintaining soil health. Keeping this in view, bacteria from habitats such as composts and soil, having at least one beneficial trait and found highly promising in previous studies, were evaluated again to see if a given strain had more than one beneficial trait. Of the 14 isolates studied, four (HIB 67, SB 24, SB 26, and SRI 77) produced crystalline parasporal bodies, three (EB 13, BWB 21, and SB 21) were positive for siderophore production, two (EB 13 and SB 21) solubilized Rock Phosphate, eight (BCB19, BWB21, EB 13, HIB67, SB9, SB21, SB24, and SB26) were antagonistic to *Macrophomina phaseolina,* and two (BWB 21 and SRI 360) were compatible with *Metarrhizium anisopliae* - a fungus pathogenic to *Helicoverpa armigera*. In antagonistic studies with *M. phaseolina*, maximum zone of inhibition was recorded with EB 13 (17 mm diameter), followed by BCB 19 (12 mm). Range of inhibition zone was 5 - 17 mm diameter on culture medium. Insect killing ability of these isolates was studied by releasing *H. armigera* neonates on sprouted chickpea seeds inoculated with the bacterial isolates. Of the nine isolates, maximum percent mortality was observed with SB 26 (66%), followed by BWB 21, SB 9, SB, 21, and BCB 19. Market sample of a Bt product from USA showed 74% kill. The plant growth promoting property of these isolates was studied on pearl millet variety ICM 155 by paper towel method. Four strains (SB9, CP8-3, HIB67, and SB21) enhanced plant growth at least on par with the reference strain of *Azotobacter* (HT54), which was 12.6% superior over the control. Based on the presence of multiple traits and their potential value in crop production, four bacterial isolates (SB9, SB21, BCB19, and BWB21) were selected for field studies for crop protection in 2006-07. Strain SB 26 did not get selected despite showing high mortality because it reduced plant growth over the untreated control.

OP Rupela

Microbial properties of cattle excrement and their fermentation products: Visits to fields of practitioners of certified organic farming (OF) reporting high yield and apparent high population of natural enemies of insect-pests prompted this study. Apparent concerns of policy makers and research managers on increased cost of crop production was to be addressed through the low-cost and biological inputs widely used by OF practitioners. A fermented broth called Amrit Paani (AP) or Jeevamrut was one such input. Microbial properties of AP and of cow dung, its major ingredients are presented here. Buffalo dung was included in the studies to learn differences in excrements of the two bovines. Fresh samples of excrement were collected aseptically and subjected to counting population of total bacteria, total fungi, total actinomycetes (indicators of soil health), P-solubilizers, *Pseudomonas fluorescens* (manager of soil borne diseases), siderophore producers (chellate iron and promote plant growth), and *Escheritia coli* (indicator of threat to human health). Data in Table 1 suggest that both cow and buffalo dung had similar population of total bacteria, total fungi, total actinomycetes, and *P. fluorescens*. Population size of P-solubilizers was undetectable in cow dung, but very high in buffalo dung ($\log_{10}$ 6.00 g^{-1} dry mass) and siderophore producers were absent in buffalo dung, but high in cow dung ($\log_{10}$ 4.99 g^{-1} dry mass). Microbiology of AP (applied to soils along with irrigation water and reported by farmers to improve crop growth) using excrements from the different bovines was quite revealing. We studied the population of different microorganisms at day 0 and day 3 under two fermentation conditions: a) flasks placed on shaker, and b) stationery culture. Data of day 3 indicated that microbial population, except actinomycetes and *P. fluorescens,* grew well in shake culture (Table 1). The counts were similar irrespective of the source of excrement. P-solubilizers in shake culture of AP of cow dung were about 10 times greater than that of buffalo dung. Noticeably, siderophore population was not detected even at the lowest dilution (Table 1) suggesting that this group of bacteria do not like aeration. Population of different microorganisms in stationary cultures was similar in the AP prepared using cow or buffalo dung. The striking difference was in the population of siderophores, which was high in the AP prepared using cow dung ($\log_{10}$ 3.73 mL^{-1}), while it was absent even at the lowest dilution in buffalo dung (Table 1).

Population of *E. coli* (which is considered a human health risk if present in consumables) was high in excrements of both cow and buffalo, and in the AP prepared using these. Since use of cow dung has been widely practiced in India for centuries for plastering floors of kitchens daily (when kitchens used to be of mud floor, practiced in rural areas even today), it is likely that Indian population is adapted to *E. coli*. Presence of high population of *E. coli* in human intestines (about one million per g excrement) is a normal phenomenon, where they are an important source of Vitamin K (absorbed through intestines). Rarely a strain of this bacterium is pathogenic to humans. However, their presence in food products is an indicator of human hygiene because disease-causing bacteria pass through excrements when a person is sick, and therefore, presence of *E. coli*, a safe bacterium – even for lab culture, suggests contamination from intestinal matter. Bacteria such as *P. fluorescens* have been reported inside plant tissue and provide induced systemic resistance (ISR) to plants in managing pests.

Table 1. Microbial population in cattle dung ($\log_{10}$ g^{-1} dry mass) and its fermented slurry ($\log_{10}$ mL^{-1}) (ICRISAT, Patancheru, 2006)

Microbial group	Dung		AP (shake)		AP (stationary)		SE
	C	B	C	B	C	B	
Bacteria	**6.78**	**6.94**	**7.44**	**7.60**	**7.28**	**7.44**	**0.146***
Fungi	**4.90**	**5.09**	**3.87**	**3.98**	**3.64**	**3.20**	**0.122*****
Actinomycetes	**5.99**	**5.65**	**<2.00**	**<2.00**	**3.43**	**4.10**	**0.460****
P. fluroscens	**<3.00**	**<3.00**	**<3.00**	**<3.00**	**4.67**	**4.67**	**0.139*****
P-solubilizers	**<3.00**	**6.00**	**5.87**	**4.77**	**6.07**	**6.02**	**0.557***
Siderophore+	**4.99**	**<2.00**	**<1.00**	**<1.00**	**3.73**	**<1.00**	**0.120*****
E. *coli*	**4.63**	**5.23**	**5.38**	**4.95**	**4.73**	**5.77**	**0.334^{NS}**

AP = Amrit Paani or Jeevamrut - a fermented cow dung slurry widely used by practitioners of organic farming; C = Cow; B = Buffalo; *, **, * = Differences are statistically significant at *P* 0.05, 0.01, and 0.001, respectively.**

Overall, preparation and use of AP is a low-cost source of consortia of several agriculturally beneficial microorganisms. As there is no apparent health risk, its use can be promoted. This should reduce dependence of farmers on purchased inoculants. Previous studies have indicated that population of some beneficial microorganisms such as *Rhizobium* can be low in fields practicing OF, and therefore be purchased from market. The studies suggested that cow dung slurry if used directly will also provide different types of bacteria. But its use as AP allowed 10 times increase in total population of some key beneficial bacteria in the 3-day fermentation. A cow provides 8 to 10 kg dung (wet mass) per day, and if used as a source of beneficial microorganisms, one animal would be adequate (as a source of microorganisms through availability of about 1000 L Amrit Paani per day, round the year) for one ha. While if perceived as source of nutrients (N, P, and K) needed for crop growth without chemical fertilizers, it will be highly inadequate.

OP Rupela

Bioefficacy of selected botanicals and their compatibility: Botanicals and microorganisms are widely accepted as eco-friendly managers of insect-pests and diseases. Focus of this study was on materials readily available to farmers and at low cost, e.g., use of neem foliage instead of neem oil. Identification of botanicals that may enhance bioefficacy of microbial pathogens of insect-pests was another focus of the study. Fruits of neem, *Anona*, *Pongamia*, and *Jatropha* have been used for insect control. In previous studies, we noted that even foliage of neem and *Parthenium* had the ability to kill larvae of *Helicoverpa armigera.* A bioproduct involving stinging nettle (*Urtica diocia*) - a weed, has been used by farmers since 1924. In previous studies, *Bacillus subtilis* strain BCB 19 and *Metarrhizium anisopliae* have shown promise for pest management, including some disease-causing fungi. Individually, both the microorganisms were compatible with most botanicals, including neem and *Parthenium*. Compatibility of these with stinging nettle is reported here. Commercially available neem oil (Sunny Neem Extracts, Pvt. Ltd., Azadirachtin 0.03%) was used as reference. Neonates of *H. armigera* and *Spodoptera litura* were used as test insects. Use of neonates was preferred over third -instars (widely used while screening efficacy of synthetic pesticides) because focus of the low-cost biopesticides is on their prophylactic use. Active ingredients in the botanicals were extracted by adding 5% of dry mass in hot water, and the filtrate was evaluated.

Efficacy of neem foliage on *H. armigera* was similar (about 58%) to that noted in the past. *Parthenium* foliage affected only on *S. litura* (Table 2). *Anona* fruit rind, *Pongamia* cake and *Calotropis* foliage did not show any effect on *Helicoverpa*. Unlike in previous studies, neem fruit kernel (NFK) showed low activity (52% on *H. armigera*, and 38% on *S. litura*). Age of fruit and/or length of period between powder preparation and use (shelf-life) are suspected to be responsible for low activity, and will be studied in future. *Jatropha* cake showed maximum activity (84%) on *S. litura*. Stinging nettle was active against both the insects (60 and 66% mortality, respectively). Appreciable reduction in insect development was noted with stinging nettle and *Parthenium* foliage in case of *S. litura.* Problems in repeatability of bioefficacy of botanicals have been noted, and seem to be associated with shelf-life, and needs to be studied in future.

Table 2. Screening different botanicals for ability to manage insect-pests (ICRISAT, Patancheru, 2006)

Treatment[a]	Mortality (%)		Mass change (%)	
	HA	SL	HA	SL
Control	**30**	**16**	**NA**	**NA**
3% neem oil	**86[b]**	**88[b]**	**-53**	**-80[b]**
***Anona* fruit rind**	**26**	**58**	**39**	**-1**
Calotropis	**28**	**32**	**5**	**-41**
Neem	**58[b]**	**20**	**29**	**-16**
Neem fruit kernel	**52**	**38**	**-7**	**-18**
Parthenium	**32**	**60[b]**	**11**	**-58**
***Jatropha* cake**	**54**	**84[b]**	**-1**	**-5**
***Pongamia* cake**	**28**	**24**	**-15**	**-24**
Stinging nettle (SN)	**66[b]**	**60**	**2.2**	**-61**
BCB 19 + SN	**76[b]**	**NS**	**5.2**	**NA**
BCB 19	**66[b]**	**NS**	**-4**	**NA**
MA + SN	**74[b]**	**NS**	**-31**	**NA**
MA	**62[b]**	**NS**	**13**	**NA**
SE ±	**9.4**	**11.1**	**22**	**23.3**

HA = *Helicoverpa armigera*; SL = *Spodoptera litura.* a = Unless stated otherwise, all botanicals were extracts of foliage (leaves and twigs) dried in shade and powdered. b = Values are statistically significantly different from control at *P* 0.05.
OP Rupela

Milestone: Mass production techniques and stable formulations developed (GVRR/OPR) 2009

Activity 6C.5.3: Develop mechanisms to cope with pest outbreaks and management

Milestone: Chickpea pod borer, red hairy caterpillar, groundnut leaf miner, and Spodoptera prediction models validated (GVRR) 2007

The populations of the aforementioned insect species are being monitored at ICRISAT center using light and pheromone traps, and field scouting. The efforts to develop population prediction models are in progress, which will be validated in the near future.

GV Ranga Rao

Milestone: Tools for the pest identification and nature of damage for different crops developed (HCS/GVRR) 2008

Insect pests damaging the ICRISAT mandate crops are being diagnosed regularly at the ICRISAT research farms, and on the farmers fields to recommend appropriate control measures. The database is being updated regularly.

HC Sharma and GV Ranga Rao

Milestone: Potential kairomones for attracting Helicoverpa adults identified (GVRR/HCS) 2009

The relative attraction of *H. armigera* females to different host plants and their volatile compounds is being studied to identify chemical components that play a major role in host plant selection by the insects. The females of *H. armigera* prefer to lay eggs on pigeonpea than on cotton, indicating the possibility of using the later as a trap crop for pest management in cotton.

HC Sharma and GV Ranga Rao

Milestone: Tools for detection and quantification of NPV samples developed (GVRR/PLK) 2008

Serological and nucleic acid-based diagnostics tests for *Ha*NPV, *Sli*NPV, and *Ambl*NPV: Nucleopolyhedroviruses (NPVs) are commonly used as biological pesticides to control insect pests over a wide array of agricultural crops on commercial basis under integrated pest management (IPM) programs. Many viral products are failing to meet acceptable standards because of poor inability to accurately assess the product quality. Therefore, it is necessary to have an efficient strategy for virus production and diagnostic tools for ensuring quality control of the NPVs: *Helicoverpa armigera nucleopolyhedrovirus* (*Ha*NPV), *Spodoptera litura nucleopolyhedrovirus* (*Sli*NPV), and *Amsacta albistriga nucleopolyhedrovirus* (*Ambl*NPV).

To compliment our ongoing NPV production activities, we produced polyclonal antibodies against polyhedra protein of *Ha*NPV, *Sli*NPV, and *Ambl*NPV infecting *H. armigera, S. litura,* and *A. albistriga*, respectively, to develop an enzyme-linked immunosorbent assay (ELISA) for diagnosis and quality control of the NPVs. Poly occlusion bodies (POBs) were purified from NPV infected insect cadavers and used for the purification of polyhedrin protein by alkali treatment, followed by differential centrifugation and isoelectric focusing at 5.6 pH. The purified polyhedrin protein was used as antigen. Three New Zealand White inbred rabbits were used for immunization with 0.5 mg ml^{-1} purified polyhedrin protein of *Ha*NPV, *Sli*NPV, and *Ambl*NPV emulsified in Freund's complete adjuvant through intramuscular route. Four injections were given at weekly intervals. A week after 4^{th} injection, the rabbit was bled for polyclonal antiserum at weekly intervals for 4 weeks, and then the animals were boosted with polyhedrin protein in Freund's incomplete adjuvant. The purity and titer of the antiserum was assessed by direct-antigen coating ELISA and western immunoblotting. The polyclonal antibodies did not react with the insect protein extracts reveling high specificity of the antibodies, and the antibody titer in various bleeds ranged between 1: 2,000 to 1: 40,000 for detecting respective polyhedrin proteins. In addition, the antibodies of each virus were cross-reacted with polyhedrins of other viruses in the study, indicating high conservation in polyhedrin protein among the three species of NPVs. The detection limits of antiserum in indirect ELISA was 20 ng of polyhedrin in case of *Ha*NPV and *Sli*NPV, whereas 8 ng in case of *Ambl*NPV. Further work is continuing towards quantification of polyhedrin for the early diagnosis of infection progress in the field, as well as quality control of NPV to accurately quantify the virus titer in the formulations.

In addition, three degenerate oligonucleotide primers (PgC, PgN, and RedPgC) were developed for the amplification of polyhedrin gene from by polymerase chain reaction (PCR). Using these primers, *Ha*NPV polyhedrin gene (~750 bp) was amplified by PCR and cloned into pUC18 vector. This sequence is being characterized, and the sequence information will be used to assess the diversity of *Ha*NPV isolates occurring in India. Attempts are also being made to develop oligomers for the amplification of hyper variable regions in *Ha*NPV genome for studying virus diversity.

Lava Kumar, GV Ranga Rao and Farid Waliyar

Milestone: Tools for the integrated pest management in different crops developed (HCS/GVRR) 2010

Development of insect pest diagnostic and management tools: Crop losses caused by biotic stresses are estimated to be in tens of billions of dollars across the world in spite of the huge investments in plant protection. Pest epidemics continue to occur causing severe hardships to poor farmers. We developed computer based insect pest diagnostic and management tools for all ICRISAT mandate crops to minimize crop losses and increase crop productivity without jeopardizing environmental safety. In this process, 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 and updated. This is an effective extension tool for NARS extension staff and scientists.

GV Ranga Rao

Synergism of host plant resistance to *Helicoverpa* with insecticides its implications for ETLs in pigeonpea: We evaluated the effect of different protection regimes on *H. armigera*-resistant (ICPL 332) and susceptible (ICPL 87119) genotypes of pigeonpea to quantify the contribution of host plant resistance in *Helicoverpa* management. The plots were sprayed at the 10% flowering, 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. Percentage pod damage was 13.2 and 47.4% in the completely protected and unprotected plots of ICPL 87119, respectively. The protected plots of ICPL 332 had a pod damage of 7.0% compared to 37.6% in unprotected plots. The grain yield was 2491 kg ha^{-1} in completely protected plots of ICPL 87119 compared to 1950kg in the unprotected plots. The protected plots of ICPL 332 yielded 2539 kg ha^{-1} compared to 1811 kg ha^{-1} in the unprotected plots. The results clearly suggest the usefulness of combining insect-resistant varieties with insecticides for management of *H. armigera.*

Synergism of host plant resistance to *Helicoverpa* with insecticides its implications for ETLs in chickpea: We evaluated the effect of different protection regimes on *H. armigera*-resistant (ICC 506 and ICCV 10) and susceptible (ICC 3137 and ICCC 37) genotypes of chickpea to quantify the contribution of host plant resistance in management of *H. armigera*. The plots were sprayed at vegetative, flowering, and podding stages with methomyl. There were three replications in a factorial design. In the untreated control plots, there were 37.7, 86.7, 11.7, 32.3, and 26.0 larvae per 5 plants in Annigeri, ICC 3137, ICC 506, ICCC 37, and ICCV 10, and the pod damage was 15.3, 29.6, 5.2, 15.8, and 13.55%, respectively. Grain yield was 1431 to 1704 kg ha^{-1} in Annigeri, ICC 506, ICCV 10, and ICCC 37 compared to 926.1 kg in ICC 3137. In the plots that were protected at the vegetative and flowering stages, the pod damage was 0.6% in ICC 506, 8.3% in Annigeri, and 11.2% in ICCV 10 as compared to 60.5% in ICC 3137, suggesting that host plant resistance in combination insecticides is quite effective in minimizing the pod borer damage. The plots that were protected at the vegetative, flowering, and podding stages had 1.7, 4.7, 1.3, 2.3, and 1.3 larvae per 5 plants, and suffered 9.5, 5.7, 0.1, 2.4, and 4.8% pod damage in Annigeri, ICC 3137, ICC 506, ICCC 37, and ICCV 10, respectively, indicating that three applications of insecticides at the critical stages provides a good protection against *H. armigera*. The grain yield was 1879kg ha^{-1} in ICCV 10, followed by 1924 kg in Annigeri, and 1663 kg in ICC 506 as compared to 1376 kg in case of ICC 3137. Further analysis is in progress to compute the economic thresholds for cultivars with different levels of resistance/susceptibility to *H. armigera.*

HC Sharma

Milestone: Tri-trophic interactions involving insects, host plants, and natural enemies for effective pest management studied (HCS) 2009

Identification of potential natural enemies of *Helicoverpa* in chickpea and pigeonpea eco-systems: Natural enemies of *H. armigera* have been collected from different eco-systems. Cultures of the parasitoids, *Campoletis chlorideae*, and *Cotesia* sp.; and the predators, *Cheilomenes sexmaculatus*, and *Chrysoperla carnea* have been established in the laboratory for further studies on bio-efficacy, and develop protocols for mass multiplication of these natural enemies for use in studies on effects of transgenics on non-target organisms, and biological control of *H. armigera*.

HC Sharma

Relative efficiency of *Campoletis chlorideae* to parasitize different insect hosts and *Helicoverpa armigera* larvae on different host plants: *Helicoverpa armigera* is a serious pest of cotton, grain legumes, and cereals. Complex intercropping systems and large scale deployment of *Bt*-transgenic crops with resistance to *H. armigera* have potential consequences for the development and survival of *C. chlorideae*. Therefore, we studied the tritrophic interactions of *C. chlorideae* involving eight insect host species and six host crops under laboratory conditions. The recovery of *H. armigera* larvae following release was greater on pigeonpea and chickpea as compared to cotton, groundnut, and pearl millet. The parasitism by *C. chlorideae* females was least with reduction in cocoon formation and adult emergence on *H. armigera* larvae released on chickpea. Host insects also had significant effect on the development and survival of *C. chlorideae*. The larval period of *C. chlorideae* was prolonged by 2 to 3 days on *Spodoptera exigua*, *Mythimna separata*, and *Achaea janata* as compared to *H. armigera*, *H. assulta*, and *S. litura*. Maximum cocoon formation and adult emergence were recorded on *H. armigera* (82.4 and 70.5%, respectively) than on other insect hosts. This information can be used to devise appropriate cropping systems to encourage the activity of natural enemies for biological control of insect pests.

MK Dhillon and HC Sharma

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) Annual

E-learning system for chickpea and groundnut insect pest diagnosis and management strategies updated and shared with Indian NARS and ICARDA.

ICRISAT Participated in Doordarshan (TV) programs on legumes IPM with emphasis on bio-pesticide usage in plant protection.

ICRISAT Participated in an All India Radio (AIR) farmers' phone-in program covering ICRISAT's involvement in Agriculture Research for the betterment of Sat farmer's livelihoods.

ICRISAT Presented a topic on innovative use of bio-pesticides on the National Geographic channel.

G V Ranga Rao and OP Rupela

Exchange of knowledge and supply of trait-specific advanced breeding lines for evaluation for local adaptation (SNN/RA) Annual

Capacity building and knowledge exchange: Eight researchers from different countries (China - 2, India - 1, Nepal - 1, Philippines - 2, and Vietnam - 1) were trained in groundnut breeding and seed production technologies. Queries related to different aspects of groundnut cultivation from farmers and students were attended to on various occasions. One CD on ICGV 91114 in Anantapur district was prepared and information shared.

International trials and advanced breeding lines: We supplied trait-specific 20 sets of international trials and 144 advanced breeding lines and segregating populations to collaborators in Afghanistan, China, Eritrea, India, Nepal, Philippines, Uzbekistan, Vietnam, and Zambia.

Variety releases/ likely releases by the NARS

China: Groundnut variety Huayn 23 was released for cultivation in the Shandong province in China. It is derived from ICGS 37. Huayn 23 produced 13.5% more pod yield over the local control Luhua 12 at 22 locations in the province.

India: The Chief Minister of Andhra Pradesh, India, Dr. Y. S Rajashekhar Reddy, in a special function at ICRISAT, Patancheru, dedicated the drought-tolerant, early-maturing, high-yielding variety ICGV 91114 to Anantapur farmers. This variety was tested in farmer-participatory varietal selection trials for four consecutive years in drought prone locations in Anantapur, the largest groundnut growing district in India. Farmers liked the variety and accepted it as a possible replacement of a six-decade old variety TMV 2. This variety was released formally on 2 June 2006 by the State Varietal Release Committee of Andhra Pradesh.

ICGV 89290 - a Spanish variety with tolerance to foliar diseases and insect pests, has been identified by the All India Coordinated Research Program on Groundnut (AICRP-GN) for its release in Zone II, comprising Gujarat and Rajasthan states of India. This variety is already released as SG 99 for spring season cultivation in Punjab state of India.

ICGV 92195 - a short-duration groundnut variety, has been proposed by Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India, was released by the Central Varietal Release Committee as 'Pratap Mungphali–2' for zone II (Rajasthan and Gujarat) in India.

ICGV 93468 - a short-duration variety, is proposed for release as 'Avtar' in Uttar Pradesh, India for spring season cultivation. The variety is already popular with the farmers and was cultivated on 59,000 ha during the 2005 spring season.

AK 303 - a confectionery variety,, selected from an F_4 population ((ICGV 88384 x JL 24) x (ICGV 88438 x ICG 5240)), has been proposed by Mahatma Phule Krishi Viswavidyalaya, Jalgaon, for release in Maharashtra, India.

During the Annual Rabi/Summer Season Groundnut Workshop 2005/2006 of AICRP-GN, 21 new varieties were proposed for inclusion in the coordinated trials. Of these, 10 varieties had either ICRISAT supplied germplasm or breeding lines in their parentage or were direct introduction (ICGV 91114, ICGV 98281, ICGV 98223, ICGV 96110, ICGV 97045, ICGV 98396, and ICGV 98412). In addition to these, 47 other lines have been included in different state-level multi-location trials.

Nepal: Nepal Agricultural Research Council (NARC) released two high-yielding varieties ICGV 86300 (as Rajarshi) and ICGV 90173 (Baidehi) for general cultivation in Nepal.

Timor Leste: After one more year of on-farm trials, the Ministry of Agriculture intends to propose two groundnut varieties, ICGV 88438 and ICGV 95278, for release in the country.

Uzbekistan: ICGV 86155 - a short-duration variety, as 'Salomat;' and ICGV 94088 - a medium-duration variety, as 'Mumtoz,' have been released for cultivation in Uzbekistan. Salomat is recommended for planting as main crop and also as double crop in Kaskkadarya and Surkhandarya provinces of Southern Uzbekistan. Mumtoz is recommended as a main crop throughout the country.

Philippines: The Ilagan Agricultural Research Station, Ilocos, has introduced ICGV 86564 - a large-seeded variety in the region. This variety has outperformed the local as well as improved varieties in the region, both, in terms of yield and seed size. It has been named as ASHA in India, which means 'Hope'. It has been introduced in the farmers' fields in the Northern province of the country, Ilagan. Farmers are impressed with its performance. It has been included in the state trials so that it gets released officially.

Ghana: The groundnut research in Asia has spill over benefits for Africa also. Recently, the Savanna Agricultural Research Institute, Ghana, released two groundnut varieties, which were developed at ICRISAT Center, Patancheru, India. ICGV 92099 - released as Gusie-Balin, is an early-maturing high-yielding variety with resistance to leaf spots. ICGV 90084 - released as Kpaniely, is a medium-duration high yielding variety with high oil content and resistance to leaf spots.

SN Nigam and R Aruna

Milestone: Breeder seed of improved varieties made available to NARS, NGOs, private sector, and farmer groups (SNN/RA) Annual

Breeder seed (25.5 t) of five varieties (ICGS 44, ICGS 76, ICGV 91114, ICGS 11, and ICGV 86564) was produced in the 2005/2006 post-rainy and the 2006 rainy seasons, and 21.6 t was distributed to different public and private sector seed producing agencies and farmers for further seed multiplication.

Milestone: Technical information and public awareness literature/documents developed and disseminated (Annual)

The 2006 issue of International *Arachis* Newsletter with 16 articles from 5 countries, and news and views items from different parts of the world was published.

SN Nigam

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 thru farmer participatory trials and village level training courses (FW/SNN) Annual

On-farm evaluation of components of aflatoxin management in groundnut: Integrated aflatoxin management trials using compost, gypsum, and *Trichoderma viride* was conducted during the 2005 rainy season in 10 farmers' fields at threevillages in Pileru area of Chittoor district, Andhra Pradesh, India. In a 100^2m experimental plot, compost (5 t ha^{-1}) was incorporated in the soil after field preparation, *Trichoderma* (sand coated 100 kg ha^{-1}) was applied in the soil at sowing and gypsum (500 kg ha^{-1}) was applied at the flowering time. The plantings were carried out during the second fortnight of July using local variety TMV 2, which is highly susceptible to aflatoxin contamination. In Anantapur district, Andhra Pradesh, India, only *T. viride* was tested at Rekulakunta village on ten farmers' fields with a plot size 100^2m. The *Trichoderma* was applied adjacent to the rows one week after germination.

From each plot, about one kg pod sample was drawn and pods were sorted based on size into small and large pods. The *A. flavus* infection and aflatoxin levels ranged between 1 - 62% and 0 -5233 µg kg^{-1}, respectively. In bulk seed, 68% reduction in *A. flavus* seed infection was observed in plots treated with compost and gypsum, over the control, which had 11% seed infection. Similarly, in large seed lots, about 53% reduction in *A. flavus* was observed with compost, *Trichoderma* and compost + *Trichoderma* + gypsum treated plots. Corresponding aflatoxin in large seed lots showed that 97% reduction in toxin level with compost + *Trichoderma* + gypsum treatment, followed by compost (23%) and *Trichoderma* (14%) over 125 µg ha^{-1} in control. However, in small seed lots, reduction in *A. flavus* infection was low (21%) with a combination compost + *Trichoderma* + gypsum application. In small seed samples, highest reduction (72%) in toxin level was observed with *Trichoderma*, followed by compost + *Trichoderma* + gypsum (41%), and gypsum (33%) as against 133 µg ha^{-1} in control. Kernels from damaged pods showed very high levels (>510 µg ha^{-1}) of aflatoxin. *Trichoderm*a, gypsum, and compost + *Trichoderma* + gypsum application showed 28 - 58% reduction in aflatoxin contamination over the control (1207 µg ha^{-1}). This trial was repeated in the 2006 rainy season on 10 farmers' fields (plot size 100^2m) in Cherlopalli village in Anantapur. The trial was harvested in Nov. 2006. Post-harvest sampling is being done for *A. flavus* infection and aflatoxin analysis, and the results are awaited.

Farid Waliyar

Low-cost agro-practices for management of groundnut aflatoxin via integrated management: To develop low cost options for the management of aflatoxins contamination in groundnut, a field trial was laid-out at ICRISAT-Patancheru during the 2006 rainy season. The trial comprised of 4 treatments (application of compost, gypsum and their combination, and untreated control), with susceptible genotype JL 24, and planted in 6 replications using randomized complete block design. Highly toxigenic strain (AF 11-4) of *A. flavus* multiplied on maize/sorghum seed was broadcasted in the field before sowing, followed by row application of inoculum at fortnightly intervals - starting from 25 days after sowing. Terminal drought was imposed 30 days before harvest to facilitate the seed infection and aflatoxin contamination. Harvesting at 110 days after sowing was done by up-rooting the plants and the produce dried under sunlight for 5 - 7 days before the pods were stripped. Post-harvest sampling for aflatoxin analysis is in progress and the results are awaited.

Farid Waliyar

Milestone: Training courses in mycotoxin detection technologies conducted for NARS (FW/PLK) Biennual

A training course in mycotoxin detection technologies for NARS will be conducted in 2007.

Farid Waliyar and P Lava Kumar

Project 7
Reducing Rural Poverty through Agricultural Diversification and Emerging Opportunities for High-Value Commodities and Products

System Priority3: Reducing Rural Poverty through Agricultural Diversification and Emerging Opportunities for High-Value Commodities and Products

Specific goal 1a: Identify key species for research and assess their factor and product markets in WCA
Specific goal 2a: Enhance production of selected fruit and vegetables through improvement of farming systems in WCA

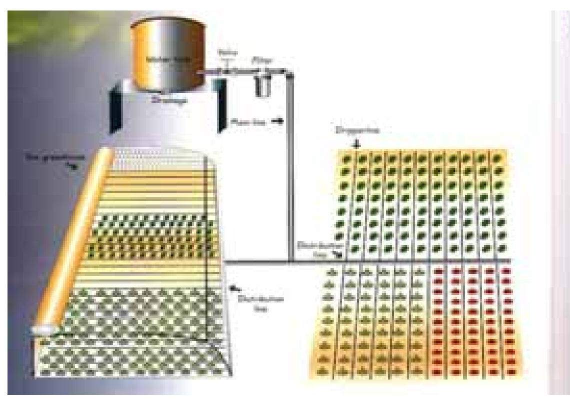
Output 7A African Market Garden technology strategy and knowledge database, developed, tested and promulgated regionally in the SAT of the Sahel (in collaboration with AVRDC and ICRAF) by 2009 and assessed in comparison with existing and new potential dryland alternatives

Output target 2007 Sahelian Eco-farm: 1st proof of concept tested and validated in Sahelian countries and report published

Intensification and Improvement of Market Gardening in the Sudano-Sahel Region of Africa

The African Market Garden
Current production systems (hand irrigation and to a lesser extent basin irrigation) are labor-intensive, imprecise and wasteful of water and energy. Productivity is very low. ICRISAT-Niamey and IPALAC developed an improved system of cultivating market gardens, called the **African Market Garden** (AMG) to reduce these constraints. The principles of the AMG derive from research carried out at the Ben Gurion University in Israel (Pasternak and Bustan, 2003). (Fig.1).

Fig. 1. AMG scheme. Daily water supply is stored in a reservoir elevated one meter above the field. Water flows through a valve, a filter, a main line and distribution lines to the field (or a greenhouse) and reaches the plants through drip laterals



The African Market Garden delivers drip irrigation, in a form that is affordable and manageable by smallholders in the Sudano-Sahelian region. Its advantages are:

- Large reduction in labor for hand-carrying water in buckets
- Less water used - water application adjusted to match crop water consumption
- Less fuel cost for pumping less water
- Even distribution of water across the plot
- Fertigation (fertilizer application with irrigation water) – more efficient
- Slow water discharge making the system suitable for both sandy and heavy soils.

Three systems were developed:

a. The “Thrifty System” is based on a 200-liter water-barrel reservoir serving an irrigated area of $80m^2$. The barrel can be hand-filled from a nearby water source. This system is suited for the very small-scale producer, mostly in communal village gardens.

b. The “Commercial System” is based on a concrete ring reservoir serving an area of $500m^2$ (Pic.1).

“Commercial system” in a Niger village. Note water reservoir on left. Woman holds bolting-tolerant Noga lettuce variety selected by ICRISAT-Niamev

c. The “Cluster System” is based on the supply of water from a large reservoir, preferably a dam, to a large number (clusters) of AMGs concentrated in one area (see Pic.2).

The Cluster system. Water flows from a dam (or another large reservoir) situated three meters above the field (not seen) through a central distribution line (center-right) and is supplied to a cluster of AMGs (right and left). The blue barrels serve as fertilizer tanks

This is the preferred system because of savings in pumps, reservoirs and energy. Concentration of many producers in one place has additional advantages such as mutual learning, joint purchasing of supplies and joint marketing.

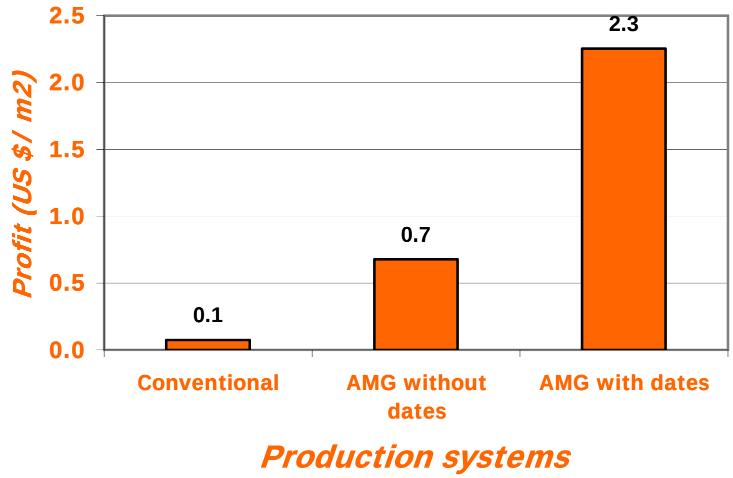
In all models the irrigated area can be expanded by adding water storage volume or by connecting additional drip systems to existing reservoirs. In the “commercial” model the volume of the reservoir is calculated according to maximum daily water demand by the crops. For example in most of the Sahel peak plant water use is about 8mm/day. Hence the volume of the reservoir that serves a $500m^2$ unit is $4m^3$.

Over the last three years ICRISAT-Niamey fostered the installation of about 1,500 AMG units of all three models in nine Sahelian countries. The number of newly installed units is steadily growing.

The AMG is easy to operate and maintain, saves energy, labor and other inputs. Significant yield increases for some crops are recorded and product quality is enhanced.
Incorporation of quality date palms varieties (possible in the Sahel due to high ambient temperatures) significantly increases the profitability of the system.

Fig. 2 gives the annual profit per m^2 of a conventional market garden, and an AMG, both planted with vegetables and of an AMG with date palms intercropped with vegetables. The area of each of the three systems is $500m^2$. Nine date palms are planted, each giving an annual fruit yield of 100kg/palm. The higher profits from the AMG resulted from both savings in inputs (labor for irrigation, fuel for water pumping, fertilizers) and from higher yields combined with better product quality.

Fig. 2. Annual profit per m² of a conventional market garden, an AMG and an AMG planted with dates



Vegetable varietal adaptation to the Sudano-Sahel

High air temperatures are the main environmental constraint for vegetable production in the Sudano-Sahel (Fig. 3).

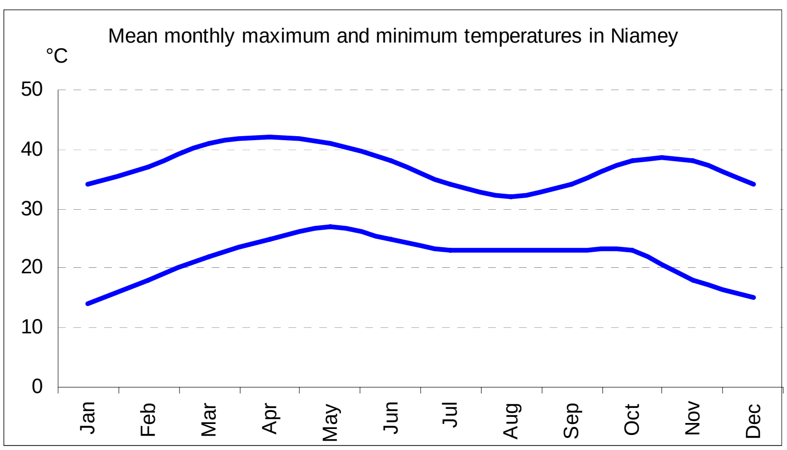


Fig. 3. Annual variation in mean maximum and minimum temperatures in Niamey-Niger. Note the cooler night temperatures from Mid October to March that is the main vegetables production season

Most vegetable varieties produced in the Sudano-Sahel are purchased from seed companies based in Europe and the USA. Many of these varieties are not adapted to the high temperatures of the Sahel. However, areas with warm climates such as Australia, Israel, California, India, AVRDC in Taiwan and others have bred heat-tolerant varieties that are more suitable for Sudano-Sahelian conditions. Over the last four years ICRISAT-Niamey has screened a large number of varieties of nine vegetables species to select those that are best adapted to the Sudano-Sahel. Examples of some of these varietal differences are given in Figures 4-7.

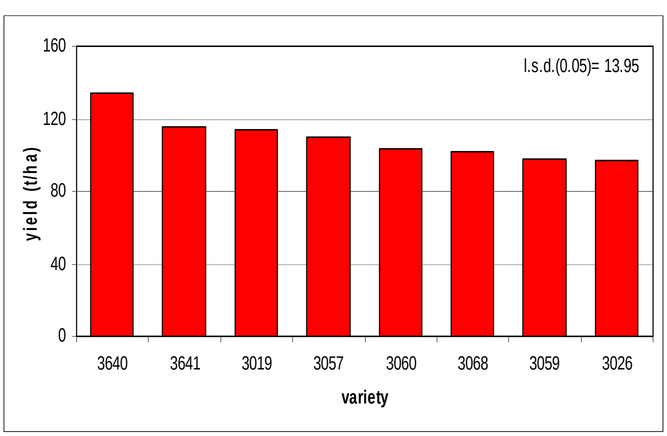
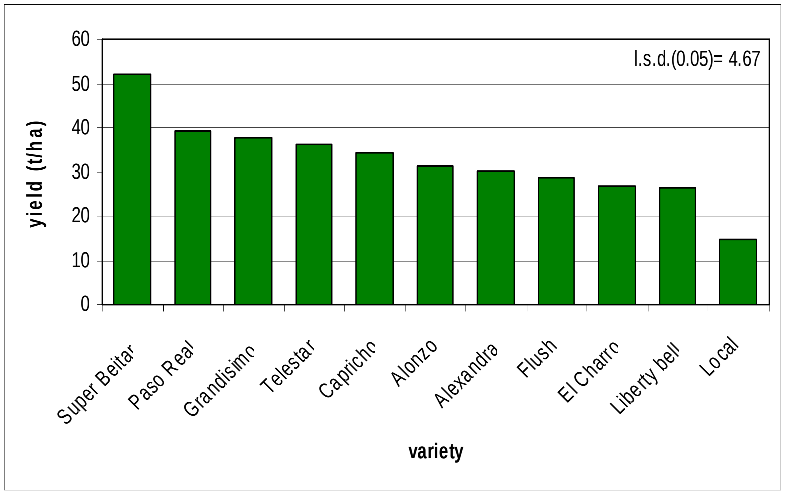


Fig. 4. Fruit yield of eight hybrid tomatoes from Hazera Company. All varieties have firm fruit with long shelf life and tolerance to a wide range of soil born diseases viruses and pests

Fig. 5. Fresh yield of 10 sweet pepper varieties compared with the yield of a local variety. Peppers were planted in December and yielded from February till May. Yield of the best variety, 'Super Beitar', was almost five times greater than that of the local variety



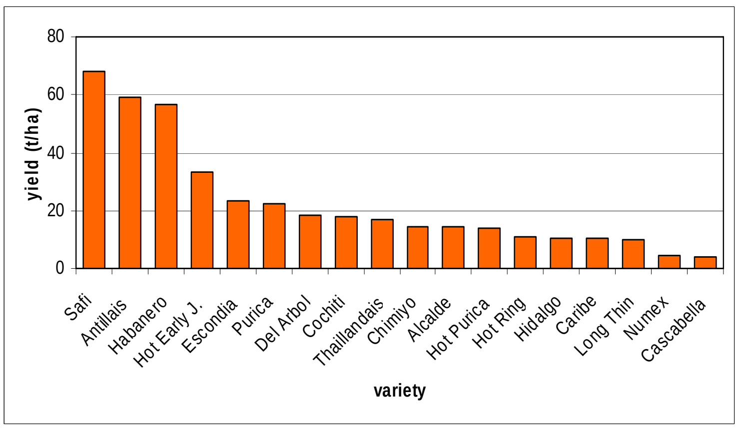


Fig. 6. Fresh yield of 18 hot pepper varieties. The best varieties were Safi, Antillais and Habanero. All three varieties are very pungent and have a square fruit shape. Anttilais had poorer fruit quality

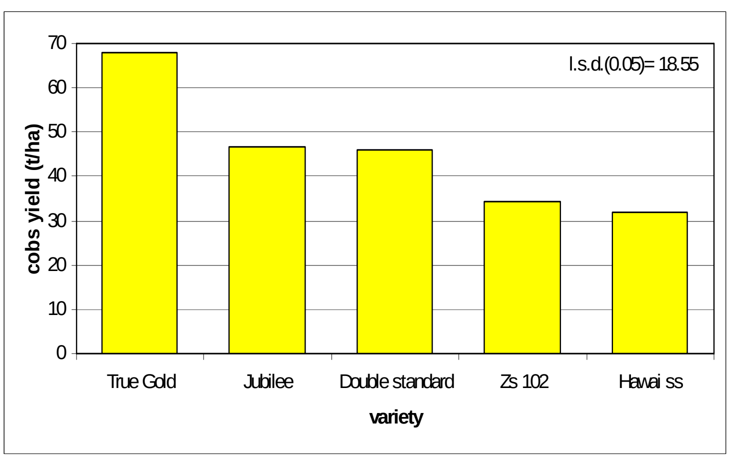


Fig. 7. Cob yield of five sweet corn varieties. True Gold, an open pollinated variety, yielded substantially more than other varieties in all production seasons

Tomatoes

Tomatoes are the most popular vegetable in the Sudano-Sahel. During the rainy season (June-September) tomato fruit set is very poor. We hypothesized that this might be due to the high night temperatures during this period. Previous research had studied the effect of high day/night temperature regimes on fruit set, finding that these regimes drastically reduced fruit set (Abdul Baki, 1991). However there was little information on the effects of high night temperatures alone (with day temperatures kept constant).

The performance of 'Xina', a tomato variety that sets fruit in the rainy season, was compared with that of a rainy season "sensitive" variety, varying only the night temperature (comparing 34°/29°C versus 34°/18°C day/night). The results (Table 2) support the hypothesis that the high night temperatures that prevail during the rainy season are responsible for the low fruit set of tomatoes during that season.
Xina had a higher fruit yield at higher night temperatures because it had more flowers and a higher percentage fruit set as compared with the Negev variety

Table 2. Effect of two day/night temperature regimes on yield, number of flowers per plant and percent fruit set for rainy-season tolerant versus sensitive tomato varieties ('Xina' and 'Negev'). The values for the high day/high night temperatures are means of hourly temperatures in a screen house. Low night temperatures were obtained by transferring pots each night into an air-conditioned room.

Temperature regime / Variety	34°/29°C			34°/18°C		
	Yield (kg/plant	Flowers/plant **(No.)**	**Fruit Set (%)**	Yield **(kg/plant)**	Flowers/Plant **(No.)**	**Fruit Set (%)**
Xina	**2.24**	**672**	**17**	**4.72**	**608**	**67.9**
Negev	**1.28**	**287**	**8.2**	**4.13**	**424**	**61.0**

The fruit quality of Xina however is very poor. It is a segregating variety with large variability in fruit size and shape. This allowed selection within the variety that markedly improved the quality of Xina fruit (Pic.3).

Selection within the Xina population resulted in larger and uniform fruit of superior quality

Onions

Onions are an economically important vegetable crop in West Africa. The variety 'Violet de Galmi' is a Grano type onion and is the preferred variety in all of West Africa. Since this variety was created in the mid-1970s, efforts to maintain varietal purity were insufficient. Many local onion producers selected their own lines from the field, resulting in great variability within this variety. In 2004 we purchased Violet de Galmi seeds from 42 well-regarded onion seed producers in Niger and compared their performance using seven different criteria. We selected a line that yielded more than 60 t/ha, compared with an average of 35 t/ha for the other lines, over two consecutive years. The bulb quality of this line is reasonable. We are continuing to select within this line for better quality, especially longer storage life and uniformity.

Table 3 gives the names of ten vegetable varieties selected so far for the Sudano-Sahel. Most of these varieties are open-pollinated, allowing producers to multiply their own seeds. This is important because hybrid seeds are too expensive for most small producers.
ICRISAT-Niamey is now maintaining and producing foundation seed of these varieties (Pic.4) and distributing them to small-scale seed producers. A regional course on vegetable seed production and storage is offered annually to reputed seed producers across the region.

Pic 4. Production of foundation seeds of selected bolting-tolerant lettuce

Table 3. Vegetable varieties selected for the Sudano-Sahel climate

Species	Common name	Selected varieties	Remarks
Lycopersicum esculentum	Tomatoes	Xina (Improved)	High yield, fruit set in rainy season. Long shelf life. Improved quality
Lycopersicum esculentum	Tomatoes	Hazera 3640	Hybrid. Firm, long shelf life, many tolerances
Capsicum annum	Sweet pepper	Super Beitar	Very high yield, large fruit
Capsicum chinense	Hot pepper	Hot Habanero, Safi,	High yielding, very pungent, square shape
Lactuca sativa	Lettuce	Maya, Noga, Aviram and Queensland	All bolting tolerant. Aviram-iceberg type
Cucumis sativa	Cucumbers	Bet Alpha	Tasty, heat tolerant, short shelf life
Zea Mays	Sweet corn	True Gold	Heat tolerant, tasty
Cucumis melo	Melon	Ein Dor	Heat tolerant, very sweet

Citrulus lanatus	Watermelon	Malali	Drought tolerant, big seeds
Moringa oleifera	Moringa	PKM-1	Leafy vegetable. Higher leaves and pod yields. Leaves are tastier than local varieties

<u>Specific goal 1: Identify key species for research and assess their factor and product markets in Asia</u>
<u>Specific goal 2c: Enhance production of selected fruit, vegetables and plant products through improvement of farming systems in Asia</u>

Output 7B 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.

Output target 2007: Exemplar watershed studies completed in four Asian countries and reports published

7B.1: Cultivation of vegetables and other high-value crops at benchmark watersheds in China and India. *Yin Dixin, RA Sharma, Somnath Roy, P Pathak and SP Wani*

To increase income of the farmers, the cultivation of vegetables and other high-value crops were evaluated by farmers at the benchmark watersheds in India, Thailand, Vietnam and China. Over the past two years farmers at the benchmark watersheds in Rajasthan, Madhya Pradesh and Andhra Pradesh have expanded areas under high-value crops like turmeric, ginger, coriander, onion, tomato, chillies, papaya, greenpeas, cabbage, cauliflower and carrot with the assured water availability. With the shift from low-value to high-value crops not only have farmers incomes increased, but it also improved family nutrition as farmer's consumption of vegetables and fruit increased.

Results from two sites are discussed:

i. Vegetable and water melon cultivation at Lucheba watershed, Guizhou province, Chin*a:* In China farmers are adopting a range of rainwater conservation and harvesting techniques and storing the harvested rainwater in underground cisterns. This stored water is now being increasingly used by farmers to grow high-value crops such as vegetables (two to three crops per year) and fruit trees,that can provide rural households with high incomes. The crops grown in the Lucheba watershed in Guizhau Province are chillies, tomato, chinese cabbage. In 2003, at the start of the project the total vegetable area in the watershed was 25.3 ha. By 2004, after twelve months of project interventions the area had increased to 37.3 ha, with accompanying increases in vegetable production and yield (Table 7B1). The increase in production enabled participating farmers to increase the proportion of their harvest that was sent to the local market. However, transport costs between the village and the market was a problem due to poor road connections between the village and the main road. The collective action that had been introduced by the project to the participating villages in the construction of rain water harvesting structures now gave additional benefits, as the villagers came together to resolve this problem. The villagers approached the project and the local government with a formula to share the cost of road improvements with collaborating farmers providing the labour.

Table 7B1. Watermelon and vegetable development at Lucheba watershed, Guizhou province, China

	2003				2004			
	Size	Total yield	Price in wholesale	Total	Size	Total yield	Price in wholesale	Total
Cash crops	mu*	T	CNY t^{-1}	CNY**	mu	T	CNY	CNY
Watermelon	300	500	600	300000	200	450	800	360000
Cabbage	170	850	560	476000	330	1750	540	945000
Tomato	110	440	440	193600	90	360	600	216000
Chili	50	112.5	1300	146250	70	210	1100	231000
Others***	50	155	1400	217000	70	220	1100	242000
Vegetable	380	1557.5		1032850	560	2540		1634000
Total	680	2057.5		1332850	760	2990		1994000

***Note:** * I mu=1/15 ha; ** 1USD=8.2 CNY; *** Other vegetable are kidney bean, squash, cucumber etc.*

ii. Vegetable cultivation at Ringnodia, Rajgarh, Bundi and Madhusudangarh watersheds, in India: During 2004–05 post rainy season, the farmers cultivated several vegetables and pulses to increase their income. Highest net returns was recorded in hybrid tomato, followed by onion, Russian gram, potato, garlic, coriander and lentil (Table 7B2). Farmers are impressed with the advantages realized due to cultivation of these crops particularly during post rainy season, and the potential to earn more income, which was not the case prior to this project.

Table 7B2. Economics of vegetables and pulses grown in Ringnodia watershed, Indore, India during postrainy season, 2004–05.

Crop and variety	Area covered (ha)	Yield (t ha^{-1})	Economics (Rs ha^{-1}) Cost of cultivation	Gross income	Net income
Lentil (Sehore 34)	2.00	0.54	4630	9180	4550
Russian gram (Mexico bold)	4.25	1.36	12000	43147	31147
Potato (Jyoti)	8.25	17.5	41000	70133	29133
Onion (Agrifound light red)	1.00	25.2	21000	63000	42000
Garlic (G 41)	1.50	7.6	30000	45750	15750
Hybrid Tomato (Avinash 2)	1.50	66.8	150000	205000	55000
Coriander (Hybrid)*	2.90	6.13	18000	30700	12700

** Green leaves yield*

7B.2: Assessment of institutional needs in watersheds for enhanced impacts
TK Sreedevi, TS Vamsidhar Reddy and SP Wani

Watershed development programs in India have evolved from a compartmental approach to an interdisciplinary approach by involving many stakeholders. With changing priorities of policy makers, responsibilities of managing such programs are being delegated to primary stakeholder institutions. In this context to achieve efficiency and sustainability of programs initiatives, various models of institutional arrangements are being tried in different programs with varied degrees of success. The current study was initiated to analyse different programs to identify drivers of success in each of the models. One of the objectives of the study is to identify/ develop a procedure/ protocol for institutional analysis in watershed development programs. For the study, institutional arrangements are captured by studying institutional structures of primary and secondary stakeholders that are evolved for the program, their roles, and their mutual interaction mechanisms. The methodology includes adaptation of different stakeholder analysis tools and participatory tools appropriately to capture formal and informal institutional arrangements.

Four programs were selected through literature review for their novelty in institutional arrangements. They are Andhra Pradesh Rural Livelihoods Program (APRLP) in Andhra Pradesh, Sujala Watershed Program in Karnataka, Indo-German Watershed Development Program (IGWP) in Maharastra and Drought Prone Area Program (DPAP) watersheds following Hariyali guidelines in Rajasthan. The institutional arrangements formalized through the guidelines were understood from project documents and discussions with key informants. Informal arrangements and manifestations of formal arrangements were captured by studying two sample watersheds in each of the programs. Data collection was from groups of representatives (661 stakeholder representatives were interviewed from 4 watershed projects, 8 watershed villages located in 7 districts and 4 states) from each stakeholder category. It was ensured that each group of respondents consisted of more than 30% of the total members of the stakeholder category.

The studies revealed that for sustaining effective institutions in villages for watershed development financial activities benefiting the members are critical. In the absence of financial activities in User Groups (UGs) neither the group members met regularly nor did they take any interest in maintaining hydraulic structures in the watersheds. The SHGs who operated micro-financing at community level were active, ensuring group momentum. Some of the other key findings are:

- Detailed studies of the institutional arrangements in four programs adopting novel approaches revealed that the new institutional arrangements adopted helped in improving community participation and equity to a certain extent. However, the foremost important finding is that the basic purpose of ensuring participation of all the stakeholders and harmonization between Panchayat Raj Institution (PRI) and Watershed implementing Agency (WIA) is far from reaching the objective of ensuring benefits for women in the watershed programs. Higher representation of women in the Watershed Committee along with the targeted income-generating activities is necessary. For sustainable participation of the landless labourers, even after completion of the project specific targeted income generating activities for these vulnerable groups are needed. In the absence of such income generating activities even their representation on the Watershed Committee did not benefit these groups and as a result their participation gradually decreased.
- The Area Group (AG) concept adopted in the Sujala watershed program was found effective for enhancing primary stakeholders participation and the existing institutional mechanism of UGs adopted in DPAP and IGWP and other programs was not sustained as these groups did not have a continuing role in the watershed management and with time their interest declined considerably affecting the sustainability of the institution.
- The innovative institutional approaches adopted by these new generation development programs have moved in the right direction except for the Hariyali program. However, still much needs to be achieved in terms of harmonizing functions of various institutions operating in the village for achieving the desired impact of watershed programs in India.
- As the Hariyali Guidelines are already under criticism by some sectors and the current study also revealed that the basic purpose of enhancing community participation, as well as equity for women are far from satisfactory. There is an urgent need to improve the watershed guidelines in India by targeting Common Watershed Guidelines for all the watershed Programs as well as keeping the WIA independent of political institutions and ensuring harmonization of the functioning of PRI and WIA. The SWP provides a better institutional model for revising the guidelines suitably to ensure better stakeholder participation and issues of women and landless members need to be addressed using the better examples from the APRLP and IGWP.
- At the national, state and district level also there is an urgent need to revise the institutional arrangements as indicated by the National Farmers Commission suggesting an apex body at national level headed by a technocrat with membership from the Secretaries representing different ministries supporting the watershed programs and subject matter experts. Similar recommendations are also made in the recent report titled “From Hariyali to Neeranchal” of the Technical Committee on Watershed Programs in India constituted by the Ministry of Rural Development. The Prime Minister has already formed the National Rainfed Authority and new guidelines for the Watershed Programs will evolve soon.

Milestone 7B.2: Working paper on institutional options and strategies for enhancing collective action and groundwater management in watershed communities.
7B.3: Impact of watershed interventions on employment generation, income, poverty and migration, at Goverdhanpura-Gokulpura watershed, Bundi P Pathak, AK Chourasia, SP Wani, SN Singh and S Raghavendra Rao

Through an integrated approach with technical backstopping, productivity enhancement and income-generating activities were superimposed on conventional watershed programs.

i. Poverty and income distribution: Before the watershed program most people in Goverdhanpura-Gokulpura watershed were suffering from malnutrition and chronic poverty. The overall development in the watershed has radically changed the scenario of watershed villages. Various poverty indicators during pre and post watershed development are shown in the Table 7B3.

Table 7B3. Status of poverty before and after watershed interventions in Goverdhanpura-Gokulpura villages, Bundi, Rajasthan, India

		Land holdings (ha)							
		Before watershed interventions				After watershed interventions			
Indicators	Reflection	<1	1-2	2-4	>4	<1	1-2	2-4	>4
No. of household		152	125	36	21	208	173	23	14
Head count Ratio	Incidence	0.13	0.09	0.054	0.027	0.0058	0.038	0.034	.005
Poverty gap Index	Depth	0.065	0.048	0.028	.014	0.024	0.014	0.007	0.001
Square poverty gap Index	Severity	0.034	0.023	0.009	0.002	0.010	0.005	0.001	0

The head count ratio in the case of marginal and small farmers fell from 0.13 to 0.0058 and .09 to .038 respectively indicating larger benefits than for large land holding farmers. The depth of poverty gap is also down in all categories of farmers. After the watershed interventions the head count ratio among all categories of farmers declined significantly and in case of large farmers it is only 0.005, which indicates that the proportion of the population below poverty line is much reduced.

In addition to conventional watershed activities, several additional income-generating activities were carried out in the integrated watershed program implemented under the Tata-ICRISAT-ICAR project, which brought significant increase in farm as well as non-farm income to the farmers. Inter-crossed analysis of data reveals that the farm income of male farmers in all categories of land holding increased gradually but in the case of medium and large farmers the rate of increment was higher than for marginal and small farmers. However, in the case of small and marginal female farmers the incremental rate was higher which could be due to their participation in the SHGs undertaking income-generating activities (Table 7B4).

After the watershed development program the farm income of male farmers in the medium and large category increased by 62.5 percent and 58.5 percent respectively whereas it was only 23.5 percent and 39.6 percent in the case of marginal and small farmers. The increments of farm income of female farmers were quite low. However, the increments are higher in case of marginal (21.7%) and small (28.2%) as compared to medium (11.4%) and large (6.1%) female farmers.

Table 7B4. Income distribution of farmers from farm and non-farm activities. (N=32)

	Land holdings (ha)							
	Before watershed interventions				After watershed interventions			
	>1	1-2	<2-4	>4	>1	1-2	<2-4	>4
Farm income (Rs per annum)								
Male	1700	2220	3200	4100	2100	3100	5200	6500
Female	1150	3550	3500	3300	1400	4550	3900	3500
Non-farm income (Rs per annum)								
Male	2500	3700	2400	2400	4100	5700	3180	2700
Female	3100	3300	2350	1500	5050	5100	3000	1900
Livestock particularly milk and milk products income (Rs per annum)								
Male	1210	1350	1500	2800	1850	2100	2700	3900
Female	1000	850	750	1500	1150	1100	1200	700
Total	12660	16970	15700	17600	17650	23650	21180	21200

Note: *The income is based on a sample of 32 respondents and represents income per person*
The income before watershed interventions is calculated on current market price to avoid inflation effect.
The income from livestock divided among male and female member in the proportion of their contribution of time for livestock management.

The results of non-farm income is in contrast to the results of farm income. The household income of male farmers increased substantially in the case of marginal (64.0%) and small (54.1%) categories while the increase in the case of female farmers were higher for the same category of farmers. Overall the data revealed that the adoption of watershed program enhanced the productivity of important crops and generated more income from both farm as well as non-farm activities. Results clearly show that if the watershed activities are properly designed and implemented it can benefit all the sections of farming community.

***ii. Employment opportunities and status of migration**:* The watershed activities have increased the working days of farmers due to various activities i.e., agriculture, horticulture, floriculture, afforestation, animal husbandry and small enterprises etc. Various soil conservation measures like water storage structures, gully control structures, mini percolation pits and gabion structures were constructed in the village, which provided additional job opportunities to the small and marginal farmers (Table 7B5).

Table 7B5. Employment opportunities (Person days per month) at the Govardhanapura-Gokulpura watershed..

	Before watershed program				During watershed program			
	Land holdings (ha)							
Name of work	<1	1-2	<2-4	>4	<1	1-2	<2-4	>4
Agriculture	7	10	10	12	10	12	11	13
Horticulture	Nil	Nil	Nil	Nil	3	3	5	6
Floriculture	0	0	1	1	2	2	3	2
Afforestation	1	0	2	2	2	2	1	2
Animal husbandry	3	2	3	2	4	3	2	1
Small enterprises								
Agriculture based	1	1	2	3	2	2	3	2
Non-agriculture based	2	2	1	1	2	3	2	3
Others	1	1	1	1	1	2	1	1
Total	15	16	20	22	26	29	28	30

During the watershed program the working days of all categories of farmer increased substantially. In case of agriculture the working days of small and marginal farmers increased by 42.9 and 20 percent respectively. Floriculture is a new activity in the area and provides additional employment to medium and large farmers. Introduction of afforestation has become a main source of income especially for the marginal and landless farmers and it provides at least 24 person days employment in a year. Animal husbandry also supports the livelihoods of poor farmers and one of the best way of generating additional income. During the watershed program the working days of small farmers increased substantially by (50%) while declining trends were noticed in the case of large farmers. The data revealed that small enterprises based on agriculture provide good income opportunities to marginal and small farmers by increasing the employment.

Migration (rural to urban) is one of the core issues in this region. The Govardhanpura-Gokulpura watershed has achieved high success in reducing migration from rural to urban areas by providing better employment opportunities to the farmers in the village itself with satisfactory remunerative work (Table 7B6). In the village both seasonal and permanent migrations were significantly reduced due to watershed program. A large decline was noticed in the case of seasonal as well as permanent migration and the decline rate was greater in case of large holding followed by medium landholding farmers. However, the sharp decline was noticed in all categories of farmers in permanent migration as compared to seasonal migration. Inter cross analysis of data revealed that the seasonal, as well as permanent migration of skilled labor in all the categories of farmers was reduced with a higher rate as against that of the non-skilled labor category.

Table 7B6. Status of migration at Goverdhanpura-Gokulpura watershed, Bundi, Rajasthan. (persons per annum)

Nature of work	Land holdings (ha)							
	Before watershed program				During watershed program			
	<1	1-2	<2-4	>4	<1	1-2	<2-4	>4
	Seasonal migration							
Skilled labor	25	18	10	7	7	5	3	1
Non-skilled labor	62	43	15	14	21	18	8	2
	Permanent migration							
Skilled labor	5	2	1	1	2	1	1	0
Non-skilled labor	12	5	3	1	3	5	1	1

7B.3: Meta-analysis of the benefits from the watershed program in India

PK Joshi, AK Jha, SP Wani, L Tewari and RL Shiyani

Efforts were made to analyze and document the benefits from the watershed program by collating information from micro-level studies to give a macro dimension. Based on an exhaustive review of 311 case studies in India, we assessed the benefits of watershed programs in terms of efficiency, employment and sustainability. The analysis showed that the benefits of the watershed program accrued more to poor income regions and in regions where rainfall ranged between 700–1000 mm than to higher income regions. The mean benefit-cost ratio of a watershed program in the country was quite modest at 2.14 (Table 7B7). Only 38% of watersheds had a cost-benefit ratio more than 2 (Figure 7B1). The internal rate of return was 20 per cent, which is comparable to many rural development programs. The watershed programs generated enormous employment opportunities, augmented irrigated area and cropping intensity and conserved soil and water resources. This suggests that the program would be a vehicle for development to alleviate poverty by raising farm productivity and generating employment opportunities in marginal and fragile environments.

The benefits of watershed programs were greater where people participation was higher. It was recognized that people participation is important not only during implementation of watershed development activities but also beyond the actual investment phase. In the absence of users' involvement, watershed programs failed to sustain themselves

Table 7B 7. Summary of benefits from the sample watershed studies.

Indicator	Particulars	Unit	No. of studies	Mean	Mode	Median	Min	Max	t-value
Efficiency	B/C ratio	Ratio	128	2.14	1.70	1.81	0.82	7.06	21.25
	IRR	Percent	40	22.04	19.00	16.90	1.68	94.00	6.54
Equity	Employment	Person days ha^{-1}, yr^{-1}	39	181.50	75.00	127.00	11.00	900.00	6.74
Sustainability	Irrigated area	Percent	97	33.56	52.00	26.00	1.37	156.03	11.77
	Cropping intensity	Percent	115	63.51	80.00	41.00	10.00	200.00	12.65
	Rate of runoff	Percent	36	–13.00	–33.00	–11.00	–1.30	–50.00	6.78
	Soil loss	t ha^{-1}, yr^{-1}	51	–0.82	–0.91	–0.88	–0.11	–0.99	39.29

Source: *Derived from various studies in India*

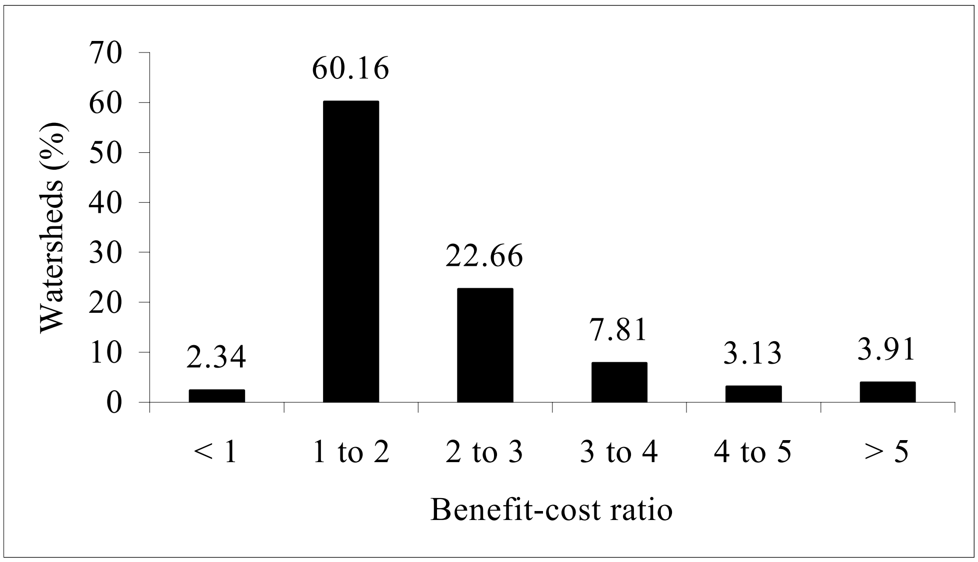


Figure 7B1.Distribution (%) of watersheds according to benefit-cost ratio (BCR).

The important conditions for people's participation were related to (i) demand-driven watershed programs rather than supply-driven ones, (ii) involvement of all stakeholders (including women and landless labor) in program implementation and monitoring, (iii) decentralization of the decision making process, (iv) involvement of elected representatives and Panchayat Raj institutions, (v) commensurate benefits of all stakeholders with their cost and (vi) establishing effective linkages between watershed institutions and other institutions such as the credit sector, input delivery system and technology transfer mechanism.

Watershed programs are one of the most important ways of bringing about socioeconomic change in the rainfed system. In some regions, it has revolutionized agriculture and the allied sector through various technological interventions, particularly soil & water conservation and crop diversification. The watershed program offers location-specific technologies and has overwhelming policy and political support. However, a major obstacle in the attainment of its potential benefits is the lack of appropriate institutional arrangements for technical backstopping and capacity building for stakeholders. Efforts to encourage stakeholders to voluntarily participate would sustain watershed development and bring prosperity in the rainfed areas, for which novel methods, policies and suitable forward and backward linkages need to be delivered.

7B.4: Social impact assessment of the integrated watershed project in Thailand and Vietnam
RP Mula, SP Wani, T Wangkahart, and NV Thang

A rapid appraisal of the social contributions of the integrated watershed project in Thailand and Vietnam was made. Findings on the biophysical aspects of the watershed were used as the starting point for investigating the impact on the agricultural and social system of farmers. Significant findings are as follows:

- Awareness and adoption of the different technological packages are high except on the installation of soil and water instruments. Less interest by farmers on the latter should be dealt with by proper inculcation of their importance.
- Modifications in farmers' agricultural systems included a change in cropping system such as addition of new crops (legumes and fruit trees), new varieties, and adjustment in the cropping calendar and some investments in aquaculture as well as poultry. Apparently, these have contributed to the improvement of the livelihood system, enhancement of community participation, and fulfillment among household members such as having more time to visit temples and some boost in their self-esteem.
- Trainings and exposure opened windows for self-help group formation and alliances/partnerships.
- A contributing factor to gains obtained in the watershed project has been due to the inculcation of the sense of ownership among the farm households. And this explains the clamor for continuous capacity building to ensure sustainability of initial gains.
- Expressed needs are technical assistance, various types of information and communication (IEC) materials, and market price information. The SWOT analysis and transects, which are validated from implementers' perspective showed a strong resemblance with farmer-respondents' needs assessment. Alongside the development of other potential resources, there were expressions of relevant extension support, market and credit assistance, and more innovations in agri-related livelihoods like pasture-based livestock and agroforestry.
- On the social aspect, an understanding of coping mechanisms can elicit the extent of problems and the ways in which affected farm households respond. This can be used as an enabling mechanism for watershed initiatives specifically in developing appropriate framework for evaluating, informing, and educating farm households.

7B.5: Mid-Term Evaluation of NWDPRA Watersheds in Andhra Pradesh, Kerala and Tamil Nadu *S Marimuthu, TK Sreedevi, AVR Kesava Rao, SP Wani, P Pathak, Piara Singh, S Nedumaran, TS Vamsidhar Reddy, R Mula and Ch Srinivasa Rao*

The National Watershed Development project for Rainfed Areas (NWDPRA) was launched by the Department of Agriculture and Cooperation, Government of India during the Eighth Five Year Plan and it is continuing during the Tenth Five Year Plan in 28 States and two Union Territories, to increase productivity and income and conserve natural resources in rainfed areas. Government of India had issued revised guidelines (WARASA-JANSAHBHAGITA) for the implementation if NWDPRA programs in the country, where it aims for improving popular participation and collective action in managing natural resources. A mid-term assessment has been called for to review the progress of the NWDPRA programs and make mid term corrections in the process of implementation wherever necessary. ICRISAT was assigned the task of a multi-disciplinary assessment of the program in the three States of Andhra Pradesh, Kerala and Tamil Nadu.

i. Objectives of Mid-Term Evaluation: Mid-Term Evaluation (MTE) aims at evaluating the progress, achievements and problems in project implementation of NWDPRA program so as to provide critical and timely information and guidelines to project management and decision support. The basic objectives of the MTE were: to assess the qualitative performance of the program, to cross examine the information furnished by states on implementation of the program, to assess the impact of the program, and to insure implementation of the program in accordance with the revised WARASA-JANSAHBHAGITA guidelines.

ii. Approaches: ICRISAT's review team adopted a fully participatory approach for evaluating the watersheds in three states by co-opting a senior member handling watershed program from the Department of Agriculture, to ensure internalization of the suggestions during the MTE. Secondly, we adopted a multidisciplinary approach with specialized disciplines including social, gender and institutional specialists along with the specialists from biophysical disciplines. In order to get a coordinated approach to undertake MTE in three states, we followed two tier approaches where a core group of experienced scientists guided the process to discuss and finalize methods to be adopted for the MTE such as sampling size, sampling method, survey instruments, analysis methods and strategies to undertake the MTE. ICRISAT teams visited these watersheds for on-site assessment of the progress made, conducted meetings and discussions with various stakeholders including rural communities, and studied the records maintained and reports prepared for various activities in watersheds. Household surveys were conducted with a well structured questionnaire by involving agricultural graduates from State Agricultural Universities. The broad aspects covered were: community organization and institutional aspects, planning aspects, implementation aspects, socioeconomic aspects, the integrated approach followed for watershed development and monitoring and evaluation.

iii. Summary of findings: The major bottleneck in the implementation of the NWDPRA programs is inadequate and non timely release of annual funds, which was found invariably across all the watersheds in the three States of Andhra Pradesh, Kerala and Tamil Nadu. It was observed that enough time-lag should be provided for Project Implementing Agency (PIA) to create awareness among the community about the program before the inception of the scheme which is necessary for improving the community participation in the program. It was found that community participation is high in watersheds implemented by Non Governmental Organizations (NGOs) compared to Government Departments. Social institutions like “User groups” are defunct in most of the watersheds which needs to be strengthened. Baseline characterization of the watershed before implementing the project was not carried out for the biophysical aspects including water resources and soil fertility status and socio economic aspects, which is necessary for identifying various watershed activities and for assessing the impact of the watershed program. Effective tools and methods should have been engaged to analyze the community needs and expectations which are missing in all the watersheds evaluated.

Water management issue is being addressed in all watersheds mainly through the renovation of existing tanks, desilting of irrigation cum drainage channels, construction of check dams, field and stone bunding mostly ignoring *in-situ* water conservation, water harvesting and recycling with efficient irrigation systems. It was felt that earthen check dams with a stone outlet would have been appropriate after looking at the land gradient and carrying capacity of drains and it could have resulted in considerable savings in the construction costs. Many of the interventions made in watersheds indicate the lack of proper technical inputs. There is need to improve the linkages with line departments, research institutions, State Agricultural Universities (SAUs) and Krishi Vigyan Kendras (KVKs) and impart technical training on soil water conservation and production enhancement technologies to the Watershed Development Team (WDT). It was found that initiatives were lacking for the protection of newly renovated tanks and desilted drains, where it is absolutely essential to find ways of establishing effective erosion-resisting vegetative cover (grasses) over tank bunds, field bunds and desilted drains to protect them from further soil erosion. It is found that Self Help Groups promoted through NWDPRA is active invariably in all three states; however, many times they were not focused on income generation activities for improving the livelihoods of landless people.

Demonstration plots on productivity enhancement technologies *viz*., new and improved crop varieties and integrated nutrient and pest management practices in watersheds needs to be introduced to strengthen the farm production system. It was felt that exposure on productivity enhancement technologies was missing in all watersheds except two watersheds in Tamil Nadu. The evaluation team found that there is greater scope for crop-livestock integration in the watersheds which may be encouraged by introducing fodder components in the farming system.

The evaluation team collected soil samples from the farmers’ fields in all the 16 watersheds, which showed that wide spread deficiencies of Nitrogen and Phosphorus in fields of Andhra Pradesh and Tamil Nadu while invariably Sulphur, Boron and Zinc were deficient in fields of Andhra Pradesh, Kerala and Tamil Nadu.

<u>Priority 3B, Specific goal 2: Management of the intensification in livestock production is improved to limit the negative impacts on the poor and the environment</u>

Output 7C. Environmental impacts of livestock intensification reduced during droughts and the dry season by developing and promoting alternative feed and fodder strategies in crop-livestock systems

Output targets 2008:
Impact of livestock on natural resources described within different policy environments and agro-ecosystems, with reference to biodiversity and primary and secondary productivity.

Need for dry season feed and fodder quantified and prioritized based on potential impact within agro-ecological zones, through participatory selection of alternative feeding strategies

9C1. Crop-Livestock Systems Development in southern Africa
Farm surveys conducted in Zimbabwe in the early 1990s revealed a farmer preference for investing in livestock enterprises in the country's extensive semi-arid areas. While crops were commonly produced for food security (to reduce the need to purchase grains), livestock were viewed as a more profitable investment enterprise. ICRISAT hired a rangeland ecologist in 2003 as the coordinator of the Desert Margins Program. One former ICRISAT economist joined the International Livestock Research Institute (ILRI) to lead their Targeting Research and Development Opportunities Program. This created a basis for initiating a review of ICRISAT's crop-livestock systems development priorities in southern Africa. This has evolved into a growing program on crop-livestock systems development. Underlying is the acknowledgement, that the potential of market-led technology development in crop–livestock systems has not been sufficiently exploited by research and development.

i. Objectives

- Assess the strategic prospects for the development of crop-livestock systems for enhancing productivity in southern Africa
- Develop and test strategies for linking livestock market development with investments in farm level inputs, especially animal feed and fodder.
- Evaluate the impact of market driven intensification of feed and fodder management on farm income and equity.
- Evaluate the impact of improved natural resource use and alternative feed systems on rangeland.

ii. Methodology
A comparative assessment of the crop-livestock systems development strategies in 5 countries of southern Africa was conducted in conjunction with ILRI: Zambia, Zimbabwe, Botswana, Mozambique and Namibia. These were chosen to reflect the variation in agro-ecologies and markets in the region. Country level experts were used to collate existing data illustrating the recent (last 20 years) trends in number, production/productivity, demand for livestock products and support to the sector as well as country specific challenges and opportunities. Results from this analysis indicated a clear role for further research and development in the livestock sector in the region. Beef production is largely stagnant while the growth in the number of goats in the region offer interesting opportunities for small scale keepers to enter in the growing regional demand for livestock products. Increased production is hampered by inputs and support services especially related to animal feed to maintain production during the dry season.

A post-doctoral scientist (livestock farming systems development) was hired to initiate a more detailed assessment of the evolution of crop-livestock systems in the SAT of Zimbabwe, focusing on market-led technology development in dry season feeding of livestock. A collaborative (including NARS and NGOs) baseline diagnosis of goat and cattle management and marketing was done through household surveys in six districts. The surveys were carried out from April to August 2005, covering the 2005/2006-production season and are summarized in Box 9C1.

Box 9C1. Unexploited agricultural growth: The case of crop–livestock production systems in Zimbabwe. *Sabine Homann and Andre van Rooye*[0]*n*

Livestock is the most important source of cash for small-scale farmers in the semi-arid tropics of southern Africa. However, with limited access to markets, farmers do not have the incentive to invest in improved livestock management. Livestock production and off-takes remain low and farmers are unable to realize the full potential of their herds. We believe that improved market access will be the driver to increase technology adoption for income growth and poverty reduction.

In Zimbabwe, a recent baseline diagnosis by ICRISAT and partners found that cash income from goats is crucial to cover day-to-day expenditures for food, education and human health. Cattle are more important for draft power and milk, and support subsistence cropping activities. Major production constraints include high mortality rates attributed to dry season feed shortages, particularly affecting farmers with small herds.

An increasing demand for livestock products in rural and urban areas offers small-scale farmers opportunities for market participation. However, the existing markets are underdeveloped, with high transaction costs implying low prices and poor access to information for farmers. The challenge is to sustain livestock production, develop more effective market facilities, and thereby increase off-take.

The potential of market-led technology development in crop–livestock systems has not been sufficiently exploited by research and development. To have an impact on incomes and poverty, we develop an innovative approach that would first evaluate local constraints in production and marketing, and then test alternative livestock markets and management strategies, with a strong linkage between private and public sectors.

The results of this initial work have contributed to the development of a larger regional program on livestock and livelihoods in southern Africa (Mozambique, Namibia, Zimbabwe). A proposal submitted to SADC, Implementation and Coordination of Agricultural Research and Training (ICART), Competitive Regional Agricultural Research Fund (CRARF) was successful in late 2006. ICRISAT will collaborate with ILRI and NARS partners to analyze small-scale farmers' opportunities in participating in livestock markets and alternative input delivery systems, and the relationship between market development and farmers' investment patterns, especially in feeding technologies. Subsets of best bet feeding technologies will be developed, tested and demonstrated under local farming conditions and multi-stakeholder participation.

iii. Main Findings & Policy Implications

During the past 25 years, livestock production has tripled and per capita consumption has doubled in most of the developing world. The developing countries accounted for 80% of the growth in global livestock production. Yet this "revolution" has largely by-passed southern Africa. Production growth in the SADC region has averaged less than 1.5% and per capita consumption of livestock products is falling. In some countries and sectors, export growth is being replaced by the pursuit of import substitution.

The failure of the livestock sector can be partly attributed to public under-investment. Though most farming systems are characterized as mixed crop-livestock enterprises, agricultural investment programs tend to emphasize crop production – even in the extensive systems and drought prone semi-arid regions. Furthermore, livestock policies have historically emphasized the pursuit of beef exports to Europe. The commercial sector has breeding and feed systems that meet European quality standards and veterinary controls to meet phyto-sanitary requirements. Public breeding and livestock management support is often targeted to large commercial producers. Programs targeting poorer smallholders emphasize disease control systems important to maintaining the national herd. Livestock management support is limited. In effect, most smallholders are viewed as residual suppliers of low value meat to the local market. The role of livestock is changing rapidly in most of the southern Africa with recent changes in governments and land reform strategies offering opportunities for small scale livestock keepers to enter in commercial markets.

Investment by small scale producers, and therefore also off takes, remain low – the question remain how to facilitate the movement from low-input extensive systems to higher in-put higher output systems. This interest has grown as these countries have begun to experience shortages of livestock products for domestic consumption. As populations, incomes, and urbanization has grown, the demand for livestock products has increased.

In Zimbabwe the production of beef has declined substantially. Fast track land reform has caused a reduction of the commercial cattle herd by 75% from 1996 to 2004, while recurrent droughts contributed to further losses of cattle in the small-scale farming sector. During the same time the goat population has increased, with more than 90% of the goats owned by small-scale farmers. Prices for goat meat are now at the same level as beef, offering opportunities for small-scale goat farmers to enter commercial markets.

Although traders are increasingly buying cattle from smallholder farmers, there has been limited improvement in animal condition and therefore product quality. The commercial market for goats and sheep remains grossly underdeveloped. Transaction costs are high and most trade remains on the informal market. Pig production remains concentrated in the hands of a few large-scale producers. While most smallholders keep poultry, almost all of the poultry meat and eggs flowing through the commercial market are derived from a small number of larger-scale enterprises. Similarly, though there have been a number of efforts to promote small-scale dairy production, most milk and related products are derived from a few larger producers.

The baseline diagnosis by ICRISAT and partners highlights that particularly goats contribute to income and food security of farmers. In the SAT of Zimbabwe only 46% of the goat keepers also own cattle. Cash income from goats is crucial to cover day-to-day expenditures for food, education and human health. Cattle are more important for draft power and milk, and support subsistence cropping activities. In addition, many women own goats and actively participate in decision-making and management. Targeting women and vulnerable groups, to achieve increase market access and investment in goat production would significantly contribute to improving household nutrition and income. Yet, farmers cannot realize the full potential of their flocks. Only 11% of the goat flock is sold and 7% is slaughtered for household consumption, while mortality at 26% results in huge losses. 93% of the farmers cited dry season feed shortages as a major production constraint - this particularly affects farmers with small herds. Most farmers started using crop residues for their goats, although the nutritional value in the dry season is low. With limited access to markets and poor market information, farmers do not have the incentive to intensify feeding technologies, and livestock production and off-take remain low.

The regional project on livestock and livelihood is developing approaches to integrate small-scale farmers into commercial livestock markets and to illustrate how increased market participation can contribute to stronger investment in feed production. The pilot schemes for livestock intensification through market-led technology change target three countries, implemented by strong partnership between public and private sectors. Best bet technologies will be selected in the course of evaluating existing market systems. An important outcome of the project is documenting the process of multi-stakeholder dialogue for linking farmers to markets. Lessons learned will be shared at a regional forum for judging potential transferability and wider application in other countries.

9C2. Identifying livestock-based risk management and coping options to reduce vulnerability to droughts in agro-pastoral and pastoral systems in East and West Africa. *Augustine A. Ayantunde (ICRISAT/ILRI), Bruno Gerard (ICRISAT), Andrew Mude (ILRI), Tahirou Abdoulaye (INRAN), Matthew Turner (University of Wisconsin) Michael Odhiambo (NGO: RECONCILE)*

There is a growing consensus that the frequency and severity of meteorological droughts in arid and semi-arid zones of Africa have increased (UNEP 2002; Dietz et al. 2004), where pastoralism and agro-pastoralism are the dominant livestock production systems. There is also a general agreement that the pastoralists and agro-pastoralists in these agro-ecological zones have become more vulnerable to climatic shocks, especially droughts (Campbell 1999; FAO 2001; UNEP 2002; Niamir-Fuller 1999). Common reasons given for this include demographic pressure, sedentarization of the pastoralists, restricted access to lands, expansion of crop fields into grazing areas and livestock corridors, poverty, lack of effective marketing infrastructure for livestock, and poor institutional preparedness (FAO 2001; UNEP 2002). Livestock as a store of wealth play an important role in drought mitigation and risk coping strategies of pastoral/agro-pastoral households (Turner 2000). For example, livestock play an important role as economic buffer to drought-induced food deficits (Turner 2000) when animals are commonly sold and sale profits go into purchase of grains for household consumption.

This new project will identify livestock-based risk management and coping options to reduce vulnerability to climatic shocks, particularly drought, in pastoral and agro-pastoral systems of East and West Africa. In addressing this, it is necessary to gain a better understanding of the changing nature of vulnerability and how it is distributed socially (gender, age, wealth) and geographically (resource access, access to markets, climate). There is also the need to understand the existing ex-ante risk management and ex-post coping strategies that pastoral/agro-pastoral households use to manage climatic shocks. A key factor that determines the degree of vulnerability to shocks in pastoral and agro-pastoral systems is their natural resource base, especially forage and water. There is therefore the need to analyze the evolution of the natural resources and the effect on livestock management, for instance livestock movement in response to droughts.

i. Project purpose

The purpose of this project is to identify intervention options (technical, policy, and institutional) that reduce the vulnerability of livestock keepers and/or communities dependent on livestock for their livelihoods to climatic shocks, particularly droughts, in pastoral and agro-pastoral systems in East and West Africa and the vulnerability of livestock to shocks. This purpose addresses the need to reduce vulnerability of both the pastoralists/agro-pastoralists and their livestock to droughts (securing livestock assets). Securing livestock assets is important in view of the roles they play in drought mitigation and coping strategies in pastoral and agro-pastoral systems.

ii. Outputs

1. A synthesis of the best available knowledge on the changing nature of pastoralism and agro-pastoralism as a result of climate change, especially drought in East and West Africa, based on scientific and indigenous knowledge prepared.
2. Understanding of the changing nature in the vulnerability of pastoralists/agro-pastoralists to droughts in East and West Africa improved.
3. Livestock-based risk management and coping options to reduce vulnerability of pastoralists/agro-pastoralists to droughts in East and West Africa and potential policy options identified.

iii. Users and beneficiaries

Users and beneficiaries of project outputs include poor pastoralist and agropastoralist producers and associations (e.g. AREN in Niger; KILA, RECONCILE in Kenya); NGOs especially those that work with pastoral and agro-pastoral societies, manage micro-loan and rural gain/livestock banks, provide emergency relief (e.g. Veterinaire Sans Frontieres (VSF), Care International, ActionAid International), donor organizations (World Food Programme, Food and Agriculture Organization), researchers and policy makers.

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)

System Priority 4: Poverty alleviation and sustainable management of water, land and forest resources

Priority 1b: Promoting conservation and characterization of under-utilized plant genetic resources to increase the income of the poor

MTP Output Target 2006: Standardized data collection methods developed

Output 8A. Nine benchmark site characterization on the improved understanding of ecosystem dynamics with regard to loss of biodiversity completed and synthesized by 2008

All the benchmark sites in the nine DMP participating countries have been characterized and a comprehensive and detailed book is being prepared on this baseline study. The degree to which the characterization was carried out varied from one country to another depending on the available expertise and the existing information from these sites. Detailed and comprehensive data are available in the various reports by each country. In all the countries, detailed lists of endemic and endangered species were prepared though the methodologies used were not uniform across countries.
Some of the highlights of this work include:

- Building of a predictive understanding of desertification, including the loss of biodiversity and ecosystem functionality in the study areas. There were differences in the depth and extent of output among countries. Some were better studied than others before the DMP was initiated. However, and more importantly, a greater understanding of desertification and its dynamics under different conditions and climatic regimes is being developed through this multi-country approach

- Inventories of endemic species were collated to illustrate the vulnerability of the diversity of various forms of plant and animal life; including soil biodiversity, fungi, higher plants, insects, birds and mammals. Various indices were used to compare degraded vs. intact or less degraded areas. These activities have also led to the identification of biological indicators (e.g. ants, birds, frogs, vegetation) that are used to assess the degree of degradation and/or desertification. Such indicators are also invaluable in monitoring the restoration of biodiversity under different land uses, e.g. commercial, communal, subsistence agriculture, or conservation land management systems. Because of the ease of observation of birds as bio-indicators, they can be used as common-language indicators to relate cause and effect of environmental degradation to extensionists, land users and managers. Unfortunately, often indices and in fact collection methodologies are not consistent

- The enhancement of biodiversity gardens through the introduction of new grasses an shrub species; the development of a biodiversity assessment manual; the development of field guides for local level monitoring; the success and applicability of the EcoRestore Decision Support System; and the progress made in the development of the C sequestration model for evaluating species potential for carbon trading

Improved understanding of ecosystem and dynamics with regard to loss of biodiversity (monitoring and evaluation)

This component is aimed at improving knowledge about the physical processes leading to biodiversity loss in the drylands, in particular the relative importance of human and climatic factors, the development of quantitative indicators of biodiversity loss, and improved monitoring techniques. Most activities undertaken under this output have been completed during Phase I. The major highlights of Phase I are summarized below:

Soil and vegetation inventories, including biodiversity have been widely investigated across the project sites (Kenya, Zimbabwe, Burkina Faso, Mali, Niger). However, levels of detail, coverage and the amount of data gathered have varied across countries. The project was successful in generating consistent baseline data across all DMP countries. Some countries have even begun modeling climate change, hydrological cycles (Kenya, Zimbabwe, Burkina Faso, Senegal, Mali, Niger), and are studying the impact of land use on the resource base, including levels of degradation, soil fertility, and changes in biodiversity and land cover. We are now planning to organize a technical conference to synthesize lessons learnt during Phase I and generate regional perspectives (West, East and Southern Africa) on the impacts of land use and climate change on the resource base. Socio-economic changes taking place in the project sites have been documented and recommendations are being formulated on potential measures for adapting to climate change, including lessons learned from indigenous knowledge and best practices in agriculture, pastoralism and agro-forestry (Kenya, Burkina Faso). Furthermore, the project has made linked together all projects operating at the same sites for information sharing to derive best practices across the eco-regions of West, East and Southern Africa.

During Phase II, some activities started in Phase I are being pursued. For example new findings have been identified to better characterize ecosystem stability. In Burkina Faso, some insect species (*Charaxes epijasius)* have been identified as potential bio-indicators for land and biodiversity regeneration. Similar work has been done in South Africa, Namibia and Botswana. In the land rehabilitation front, scientists aided by rural communities have shown that land cover could be regenerated after a very short period using the half-moon technology. Land vegetative cover was 24% on control plots versus over 82% on plots treated with half moons on lateritic or silty glacis. With the help of rural communities medicinal biodiversity has also been restored using Ikat at some benchmark sites.

The biodiversity garden of the desert in Mali has been enhanced by the introduction of several new grass and shrub species: *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*.

A biodiversity assessment manual has been developed and published by ICRAF. A data analysis workshop was organized with participants from Burkina Faso, Mali, Niger and Senegal. A strategy for upscaling adoption of *Ziziphus mauritania* in the Sahel has been developed for Burkina Faso, and can be applied in other DMP countries.

An excellent study covering general household information and population demography, security of land tenure, rangeland and livestock resources, farming practices, marketing, knowledge base of population, institutional support, access to credit, coping strategies, infrastructure, finances, education and health, labor, and monitoring system has been conducted in Namibia. *Livelihoods in the Eastern Communal Areas (Otjozondjupa and Omaheke regions), Namibia: A baseline for future reference* is a combination of a desk study and the results of extensive qualitative interviews in all nine pilot areas. A series of posters on "Socio-economic survey of the eastern communal lands of Namibia", focusing on all nine pilot areas has been developed and distributed to communities and development agents. The challenge now is how target populations and decision-makers can use this socio-economic data for improved decision-making at different levels.

A field guide for local level monitoring in the western parts of the project area has been developed. About 100 farmers from four pilot areas have been trained in the use of the field guide. Most of these farmers are in the process of implementing the local level monitoring system. The project has provided considerable backstop support to the newly trained farmers in implementing the system. A first combined session with selected farmers was held where results from the system were synthesized, analyzed, and constraints in implementation were discussed.

The success and applicability of the *EcoRestore* DSS done in Namibia depends largely on the ability to regularly update the existing database. DMP Namibia supported the Namibia Agricultural Union in conducting 54 additional case studies for inclusion in the DSS. The School of Environment Sciences and Development of Northwest University (Potchefstroom campus) has been contracted to incorporate these case studies into the existing database. FIRMs (Forum for Integrated Resource Management) have been established in all nine pilot areas and are at different levels of operation. In most pilot areas integrated workplans have been developed and incorporated into the constituency development plans of the different regions. A very successful donor conference was held in Okakarara where priorities of the pilot communities were discussed and financial support for their workplans have been solicited. One of the major challenges in Phase II will be to ensure that the newly established FIRMs in each of the nine pilot areas becomes fully operational.

Four conservancies (economically based system of sustainable management and utilization of game in communal areas) have been officially established and gazetted in the pilot areas during 2005.

South Africa has selected two provinces, i.e. Northwest and Northern Cape as they border Botswana and Namibia (two DMP countries); and teamed up with these two countries to enhance its field work. Such work included data analysis, flora and fauna surveys, and population mapping and socio-economic inventory. This led to better exchange of knowledge between stakeholders on assessment of soil degradation and integrated biodiversity management (soil and vegetation) with a resulting reduction in grazing pressure on the land; better understanding of ecosystem stability; and greater stakeholder participation in the three countries. Farmers' indigenous knowledge related to sustainable use of *Rooibos* tea has been documented, and farmer experimentation to restore biodiversity in *Rooibos* plantations enhanced. More endangered plant species have been identified and farmers made aware of species diversity. The teams also organized a workshop to record farmer practices in adaptation to climate change. Transects were set up to monitor grazing impact on biodiversity and restoration (Mier). A simplified quantitative vegetation change measurement system for application by extension agents and farmers, is under development by IES in Zimbabwe.

Climate-forcing gas emissions and development of carbon and nitrogen budgets for land-use systems have been documented in Senegal and Mali in collaboration with CEH. The influence of land use on the emissions of greenhouse gases from soils, in particular nitrous oxide and methane, the evaluation of biodiversity and biophysical sustainability indicators for desert margin ecosystems, the development of C sequestration model for evaluation of species' potential for carbon trading will be the emphasis of the collaboration between ARIs and IARCs through the Scientific and Technical Advisory Team (STAT) soon to be established. Activities will cover the following:

Climate-forcing gas emissions from land use options in Mali
Emission inventories are key to global modeling studies and environmental policy development. Reasonable estimates of sources, strengths and distribution as well as trends in time, is a prerequisite for selecting cost-effective environmental policy packages and carrying out realistic studies on projections of future emissions. Quantification of above-ground carbon dioxide sinks and sources has so far received the major international effort; but soils are now being recognized as a major under-researched component in the system.

There are large uncertainties in the current annual emission figures for nitrous oxide (N_2O) and methane (CH_4) from soils. It has been estimated, for example, that the uncertainty in the current global emission of N_2O from agricultural sources may be larger than 100% (Olivier and Berdowski 2001). Agriculture is by far the largest source of N_2O, contributing 85% to the global anthropogenic total in 1995; with synthetic fertilizers and animal waste contributing approximately equal amounts to direct N_2O emissions. There are very few data on emissions of these gases from sub-Saharan Africa or dryland agroecosystems.

Soil emission fluxes are tightly linked to land use management through the impact of natural and synthetic fertilizer application, tillage, irrigation, compaction, planting and harvesting. The aim of our study is to measure nitrous oxide and methane emissions from a range of land management options in dryland African agroecosystems. Carbon and nitrogen budgets will be evaluated in a cereal/legume field trial in Mali in which N_20 and CH_4 emissions are being measured. Additional measurements by CEH will include estimation of microbial biomass and microbial activity. This work will improve our understanding of soil nutrient dynamics: turnover of litter and organic matter, and the relationship between soil microbial activity and the emission of climate-forcing gases.

Biodiversity and biophysical sustainability indicators for desert margin ecosystems
This activity has commenced with a desk study of the current state of knowledge of soil quality assessment and evaluation of sustainability of land-use systems in the desert margins. The study has generated a review paper on the potential of carbon management to improve biological condition in land use systems in dryland sub-Saharan Africa (Hall, N.M., 2004, in preparation). This review highlights the need for further research into useful indicators of soil

biological condition as a prerequisite for evaluating sustainability of land-use in the desert margins. CEH is following up on this identified research need by developing a relevant research program with ARIs and NARS.

Development of C sequestration model for evaluation of species' potential for carbon trading
CEH work also begins in Senegal with an analysis of carbon sequestration in tree biomass and soils. This work builds on former collaboration with ISRA (Dakar) on the biomass production and nutrient use of nitrogen fixing trees (Deans et al 2003). The DMP collaboration will involve development of protocols for assessment of carbon stocks in forest systems. CEH intends to use baseline information on common tree species in the West African parklands to develop a C sequestration model that can be used to evaluate species' potential for adoption in carbon trading projects.

There has been increasing interest in the potential revenues that smallholder farmers and village-based communities may derive from the trading of carbon credits accrued through tree carbon sequestration, either through the Clean Development Mechanism, or through voluntary trading mechanisms. This work will commence with an evaluation of carbon sequestration in woody biomass and soils at a forest field station in Senegal. It is proposed that the model be field tested in village based systems in Phase II with an evaluation of existing carbon resources. While this may present an alternative livelihood option in dryland agroecosystems, a study of livelihood risks and benefits of tree planting for carbon sequestration would be integrated in this study.

Some agroforestry technologies have been promoted at most DMP benchmark sites for the involvement of rural communities such as shown in Table 1. Up to 12623 Ziziphus tree seedlings have been produced and planted in more than 25 ha.

In Niger, more than 1000 ha of rehabilitated lands have been planted with grasses and 50,000 seedlings of Ziziphus and Acacia senegal planted at the project sites with the participation of rural communities.

A manual or guide on birds found in the benchmark sites has been produced and will be published. The fertilizer microdosing technology is being promoted in Mali, Burkina Faso and Niger. New activities have been established aimed at providing alternative livelihoods to rural communities bordering the habitat of the last remaining giraffes of West and Central Africa as well as to provide more browse to the giraffes.

In Senegal, agroforestry technologies are being upscaled, with over 350,000 tree seedlings of *Ziziphus mauritania* produced, new home gardens and the African Market Garden established in rural communities, and a number of sites put under 'mises en defens' and/or natural communal reserves by over 20 rural communities using the local development plans approach. This follows a technology transfer model developed by the program and its partners as described in Fig 1. In this model, local experts play a key role and are used as change agents.

The Program in Zimbabwe has identified, through extensive participatory approaches, a number of alternative livelihoods and is currently building on these at the sites. These include production and marketing of Mopane worms, livestock, crops and cropping systems. Interventions include policy reviews regarding their adequacy, knowledge of such policies and contribution by community groups. Consultations with partners confirmed opportunities and challenges previously identified through PRAs and biophysical assessment. Participatory processes were used to identify community interest groups and assess intervention needs. Additional studies were conducted to gather information on indigenous knowledge and practices: Mopane worms, woodlands and grasses, animal disease control, and use of wetlands. Areas of critical degradation were identified at village level in the three sites and degradation processes discussed. This improved the understanding of degradation levels and processes at both community and institutional levels.

Systems Priority 4a: Integrated land, water and forest management at landscape level
Systems Priority 4d: Sustainable agro-ecological intensification in low- and high-potential areas

MTP Output Target 2006: Meta-database for historical research in WCA established

Output 8B. 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 annually and strategies formalized by the end of the DMP Phase III in 2009

The DMP focused on the development and adaptation of the strategies for conservation, restoration and sustainable use of degraded agro-ecosystems. These included the rehabilitation of degraded lands using micro-catchments, half moons, the zai system, fertilizer micro-dosing technologies, reseeding with grasses, forages and trees such as *Ziziphus mauritania* and *Acacia Senegal*.

In West and Central Africa, Best bet technologies for improved soil, water, plant, livestock and nutrient management (viz. fertilizer micro-dosing, zai system), as well as the sustainable alternative livelihood options have been identified and proposed for adoption to rural communities living in the desert margins. These include the African Market Garden (AMG), the Sahelian Eco-Farm (SEF), the Pomme du Sahel being promoted in West and Central Africa. More than 50,000 ha of degraded lands were rehabilitated using *A. Senegal and Ziziphus Mauritania*. Approximately 200,000 seedlings of Pomme du Sahel were grafted and planted. More than 1800 African Market gardens were disseminated. There is an estimated 50,000 families in these WCA countries who benefited from these techonologies through additional income generated

In East and Southern Africa, one of the greatest achievements in the region was the development of the FIRM approach – the Forum for Integrated Resource Management – a strategy to build the capacity of local people to become the informed decision makers of their own development process. The level of its adoption in three of five ESA countries is testimony to its success. Apart from this, an array of improved NRM tools and technologies were developed, tested and are ready for landscape level scaling out. Various alternative livelihood strategies were identified and evaluated for further dissemination during phase III. Benefits to stakeholders include: greater understanding of the dynamics of the degradation process, procedures for identifying and developing improved NRM strategies, improved models of participation, participatory impact assessment; improved natural resource management strategies were developed to cope with degradation of rangeland, depleted soil in crop systems; improved technologies were developed for rehabilitation of degraded land, sustainable harvesting strategies of natural populations (rooibos tea, mopanie worms, gum Arabic, honey etc); direct benefit to farmers at this stage already are impressive – existing markets can be more effectively exploited with improved varieties, higher quality produce, and more consistent harvests through improved land/crop/livestock management strategies, and finally as improved policies are drafted – new procedures and technologies may become institutionalised. The real benefits to the range of project partners and target populations will only be realized during the next few years following the large out-scaling of the program outputs.

Introduction

The Desert Margins Program (DMP) works to arrest land degradation in Africa's desert margins (see Figure 1) through demonstration and capacity building activities developed through unraveling the complex causative factors of desertification, both climatic (internal) and human-induced (external), and the formulation and piloting of appropriate holistic solutions. The wider objective (Goal) of the DMP-Global Environment Facility (GEF) project is to conserve and restore biodiversity in the desert margins through sustainable utilization. Its specific objective (Purpose) is to develop and implement strategies for conservation, restoration and sustainable use of dryland biodiversity (to enhance ecosystem function and resilience).

The activities DMP-GEF Phase II focus on implementation of best-bet technologies already identified through the characterization of benchmark sites in Phase I. This is in line with the recommendations of DMP Steering Committee of April 2005 held in South Africa to plan for activities of DMP-GEF Phase II. At this Steering Committee, a number of best-bet technologies were identified for East and Southern Africa (ESA), and West and Central Africa (WCA). For ESA and WCA, the best-bet technologies identified for up and out scaling are as follows:

East and Southern Africa

• Rangeland/livestock management options
• Restoration of degraded lands
• Improved land, nutrient and water management & crop/livestock interactions

West and Central Africa
• Pomme de Sahel/tree seedling production
• African Market Gardens
• Soil fertility and water management/fertilizer micro-dosing
• Other technologies for up-scaling are mis en defens, land rehabilitation using indigenous species and live fences.

The best-bet technologies being implemented in the DMP participating countries mainly address testing and implementing technologies/strategies for conservation, restoration and sustainable use of degraded agro-ecosystems (Output 2) and testing and promotion of sustainable alternative livelihood options (Output 4). Other technologies being implemented address capacity building (Output 3) and participation of stakeholders (Output 7). The list of the technologies being implemented in the DMP participating countries and their main features are summarized in Table 1. Technologies that address the problem of land degradation include management of degraded land using delphino plow, half-moons and seeding of woody and herbaceous plants, management of protected areas ("mis en defens"), improvement of rangeland productivity, rehabilitation of degraded lands through tree planting such as *Acacia senegal* and eucalyptus, and local level monitoring (LLM), a tool for farmers to collect information on land use indicators. For sustainable livelihood options, a number of technologies being implemented in many countries in West and Central Africa include promotion of Pomme de Sahel, promotion of African Market Gardens, and planting of gum arabic. Use of soil/water/nutrient models for dryland crops, fruit trees, bee keeping and honey production are being promoted in Kenya as alternative livelihood options while processing of Mopane worms is the main technology that addresses alternative livelihood options in Zimbabwe. The Forum for Integrated Resource Management (FIRM) approach, together with LLM for improved decision making by livestock farmers is being implemented in Namibia and FIRM only in Botswana to empower local community in managing their natural resources. To create awareness and build capacity of the youth, environmental education is being organized for schools in the DMP project sites and surroundings in South Africa. Many of the technologies being implemented are already showing impact in the project sites and many exhibit great potential in arresting land degradation and in turning desert of barrenness into oasis of fruitfulness. Land degradation control and conservation of the biodiversity of the desert margins ecosystems is the way forward to combat desertification. These best-bet technologies therefore target enhancing the resilience of ecosystems to stress and disturbances, and also aim at providing options to farmers to improve their livelihood and escape poverty, which is a major cause of ecosystem degradation.

Some major constraints in up-scaling the best-bet technologies include the high cost of implementation and dissemination on a large scale, for example, control of land degradation using water harvesting techniques for trees and pasture production, and rehabilitation of degraded lands using delphino plow. There is also the problem of rangelands being reclaimed from grazing by livestock in view of the fact that they are communally owned. Tree planting technologies also face the risk of erratic and low rainfall, which may affect the growth and establishment of trees.

Up-scaling of the various technologies in this report has enjoyed very strong participation of an array of stakeholders (farmers, community based organizations, non-governmental organizations, government ministries and extension services, and research institutions). The involvement of these stakeholders is an asset for the sustainability of these technologies. In many countries, there are other projects involved in the implementation of the technologies, which portends well for their sustainability. High level visits to DMP sites have been reported in some countries, for example, Mali where the Prime Minister visited African Market Gardens sites in Gao (North of Mali) and recommended large scale dissemination of the technology.

This report presents the best-bet technologies being implemented in nine DMP countries. For each technology, the basis of its success, its implementation, up-scaling of the technology, contribution to the overall DMP project goal and objectives, and projected potential impact have been given.

Best-bet technologies in East and Southern Africa

A. South Africa

<u>1. The context</u>

Rangeland degradation due to overgrazing by large and small stock is a serious problem in arid and semi-arid regions, especially during drought and high-risk periods. Poor vegetation cover and low production and less palatable species composition already characterize many of the degraded areas. Restoration of these degraded areas can either be through the implementation of better grazing strategies (also referred to as active or passive restoration practices) while other areas have passed the threshold of natural recovery. The production potential characterized by increased vegetation cover and biomass will only take place if active restoration practices are implemented. Rangeland managers and land users/farmers often do not have the knowledge of how to restore these degraded areas, either by passive or active means. If restoration practices are not implemented, either through better grazing strategies (passive restoration), or active intervention, such as re-seeding and cultivation of the degraded soils, or the combating of shrub/bush encroachment, then degradation will increase with many negative consequences, such as further decrease in vegetation cover, increase in bush or shrub encroachment, higher erosion and ultimately to poorer livestock production. Higher degradation will also lead to increased poverty and impact negatively on the socioeconomic structure of the land users and communities as a whole. The problems around land degradation and the impacts on the bio-physical and socioeconomic conditions have been widely described in many publications.

2. Description of the technology/strategy

In two DMP target areas of the North-West and Northern Cape Provinces in South Africa, the effect of land degradation has been identified and strategies (active and passive) to restore these lands have been implemented on different scales. To make the land users/farmers aware of the land degradation problem and to educate and train them on how to restore these areas, restoration demonstration sites have been established in the different bio-climatic zones. These include savannah, shrub land and desert-like areas with different problems, such as the encroachment and thickening of woody species (bush encroachment), the loss in vegetation cover and palatable, high productive species (especially grasses for the grazing animal) and the formation of bare and denuded patches in the different biomes, including savannah, grass and dune areas.

2.1 Improved rangeland management and restoration strategies through demonstration

2.1.1 The basis of the technology's success

The establishment of demonstration sites is very successful, especially in areas where farmers own the land. If they implement these improved rangeland management and re

storation technologies, they will indeed rehabilitate their degraded land, which will lead to increased livestock production and biodiversity. The farmers will also increase their economic outputs, which will lead to better livelihoods. The long-term monitoring and data collection activities by researchers and extension staff also increases a better understanding of these complex systems and the demonstration of the results, helps to convince farmers to apply and adopt these rangeland improvement strategies.

In areas where farmers do not own the land, due to other policy and land tenure systems, it is not easy to convince farmers to invest in better rangeland management strategies, mainly due to a lack of funds and high poverty in these areas. This is especially true for active restoration technologies, as farmers do not have the financial means to buy seed or herbicide or have access to a tractor and cultivation implements.

Farmers, land managers and ecologists (researchers and practitioners) in both the agricultural and conservation areas where these demonstration sites have been implemented, are actively involved in the management and monitoring of the sites. All stakeholders are very positive about this approach and think it necessary to have such reference sites.

2.1.2 How is it implemented?

To make the land users/farmers aware of the land degradation problem and to educate and train them on how to restore these areas, restoration demonstration sites have been established in the different bio-climatic zones in two DMP target areas of the North-West and Northern Cape Provinces in South Africa. Demonstration sites include both passive and active restoration technologies. The passive restoration demonstration sites are characterized by 20 m x 100 m exclosures with limited grazing (only in winter) in areas that are degraded at different levels (high, moderate and light) and adjacent areas that are still being grazed by cattle or game. These exclosures and adjacent grazing areas are established in three land use types, ie, communal system (open, free for all grazing), commercial (paddock and privately owned) and conservation area (game controlled). The vegetation composition (herbaceous and woody), above ground biomass production, soil seed bank and some invertebrate actions (eg, ants used as bio-indicators), as well as soil properties are being monitored on a continuous basis over the long term. The influence of grazing (in the still grazed plots) and the possible restoration (recovery) potential in the exclosure is being demonstrated to farmers, extension officers and scientists, as well as the effect of different land uses. Rainfall, one of the main drivers of rangeland dynamics and management, is also monitored at each of the sites.

The research data (vegetation, soil, bio-indicators, etc) serves as evidence of how these plots react to different grazing and management strategies and is used to demonstrate the effect on both the soil and vegetation. Demonstration plots are used in awareness, training and education workshops held with farmers and extension to try to convince the land users/farmers to implement and adopt better rangeland management strategies.

Active restoration demonstration sites are also implemented. These include areas that have been cultivated with a tractor and implement, and re-seeded with high productive, palatable and climax type of species to increase vegetation cover, and improve the production potential for grazing animals. Other areas that are characterized by increased thickening or encroachment of shrubs and/or bushes, causing a decrease in grass cover, active interventions have been implemented by the application of herbicide to control the woody species. The restoration and recovery of these areas, after the implementation of bush/shrub control mechanisms, are carefully monitored. These sites also act as demonstration sites to other farmers, as well as extension staff and researchers, in order to promote better rangeland and livestock management practices. In areas that have passed the threshold of self (natural) recovery and are characterized by open and denuded areas, such as the open dunes of the Kalahari or bare patches in the savannah, shrub and grassland areas, different active restoration technologies have been implemented over the short and long term. These include the cultivation of the area to break the hard crust of the degraded soil, followed by the re-seeding of species adapted to the environmental conditions of the region, or just the application of brush-packs (branches of woody species) on the open and denuded areas.

2.1.3 Up-scaling the technology

Demonstration sites have been used in up- and out-scaling activities targeted to all stakeholders, including land users, farmers, researchers, extension and policy makers. Workshops and farmers' days are being held at the different sites. The success of this approach resides in the fact that they are "on-site" or "on-farm" in the areas where they have to be implemented by others. Courses by trained personnel on rangeland management and livestock improvement strategies, restoration technologies, biodiversity aspects, farm planning, soils, vegetation and other ecosystem aspects are presented at the demonstration sites. These workshops and courses are being attended by farmers and other land users/managers. Documentation and course material is also given to farmers.

2.1.4 Contribution to the overall DMP project goal and objectives

Nearly all project outputs are being addressed through this approach discussed above. These include monitoring and evaluation (Output 1), testing and implementation (Output 2), capacity building (Output 3), improvement of livelihoods (Output 4), up- and out-scaling of natural resource management (NRM) options (Output 5), policy frameworks (Output 6) and especially stakeholder participation (Output 7). Many activities are also being covered by the use of demonstration sites.

2.1.5 Projected potential impact

The impact of this approach is expected to be widespread. It will contribute to an increased income or a reduction in poverty of the farmers and contributing communities, increased bio-diversity in degraded rangelands, increased capacity of all stakeholders involved (farmers, extension, researchers, policy makers, etc.), as well as the implementation of improved rangeland management systems and combating of desertification. Thousands of hectares will be improved and will contribute to an increase in biodiversity and better NRM options.

2.2. Environmental education

According to popular belief, desertification only affects people living directly from natural resources. The fact however is -- desertification of natural resources affects a large number of the population of South Africa. People, especially the youth, are often unaware and mostly ignorant about the threats to biodiversity and ecosystem stability.

Environmental education has a huge impact on information transfer concerning faunal and floral existence and biodiversity in the country. This information especially favors youth groups from previously disadvantaged areas (mostly in rural areas) who had very limited access to formal environmental education in the past. According to national legislation, environmental education should form part of the annual school curriculum for some subjects and this is where the DMP project supplements the curriculums to a great extent.

2.2.1 The basis of the technology's success

The strategy/approach was tested and evaluated at various locations throughout South Africa. Environmental education not only influences the children who are directly involved with it, but also teachers and parents. This leads to awareness creation expanding through word of mouth. Up to now a total number of 15 schools, 30 teachers and approximately 1500 children were reached through this project.

2.2.2 How is it implemented?

Participants in the project contact schools and organize information sessions, either practically in the field or through slideshows and demonstrations at schools. In some cases other partners are involved to act as instructors or to supply technical support. The following institutions and partners collaborate in the environmental education in the DMP target sites in South Africa:

- National and Provincial Department of Agriculture
- Universities, especially post graduate students of the North-West University
- Local municipalities
- Private individuals and consultants

The strategy/approach used during the various sessions include information sharing (visually/audibly), information sharing (practical exercises), question and answer sessions, and monitoring of the effect of environmental education through evaluation and re-evaluation.

Holistic approaches are used when informing children about the environment. Information is given about soil properties, plant and animal species and their response to various environmental conditions. All the information eventually leads to a better understanding of system changes during degradation, desertification, conservation and restoration. Visual and practical sessions are used to increase their understanding and to involve the children to actively participate. At the end of a session the children are instructed to build a model of a farm including references to good, stable systems as well as degraded systems. These models are used to evaluate the children's knowledge after information sessions. Questionnaires are used to determine the impact the sessions had had immediately after it is completed as well as a re-evaluation at a later stage to determine sustained knowledge.

The most important lesson learnt during the implementation of this approach was that schools and teachers should be involved during all stages of the planning phase of information and practical sessions. Information sessions should be applicable to the environment in which the children live as there is no interest for children living in a semi-desert to learn about ecological systems in wetlands. The transfer of information from specialists to children should be as interesting and practical as possible to ensure attention and a positive attitude towards these sessions. In some cases environmental education is carried out through one contact session, but cases where it takes the form of an excursion, technical support such as transport and meals should be well organized.

2.2.3 Up-scaling the technology

Up-scaling of this strategy/approach will be carried out by reaching more schools in the target areas as well as the rest of the country. This could be conducted by formalizing the information used in contact sessions into training packages and distributing it to schools and other youth organizations.

At this stage schools are identified due to their geographical position. Only schools situated in target areas were identified and used up to this stage, but in the future, schools and children on the edges of target areas will also be included. This will cause the approach to expand rapidly from the target areas through the rest of the country where the desert margins are applicable.

Environmental education is definitely a strategy/approach which can be implemented in other countries. In some of the Desert Margins youth organizations of partner countries are already involved in natural resource management on a smaller scale. Implementing this approach can lead to large scale involvement, capacity building and creating awareness about problems and solutions concerning natural resources and the degradation or desertification thereof.

2.2.4 Contribution to the overall DMP project goal and objectives

This strategy/approach plays a small but significant role in improving rural livelihoods (Output 4) and food security in South Africa. Through environmental education, the first brick is laid in children's views, expectations and treatment of the natural resources and biodiversity.

Through environmental education a contribution is made to the objectives of the Desert Margins Program by developing a better understanding of the causes, extent and severity of land degradation in natural grazing systems in the Desert Margins. Through practical sessions the exchange of knowledge about the environment is carried out among children and also between specialists and children. Coupled with this is the fact that the target groups are involved in planning and execution of the information sessions and ultimately leads to an increase in capacity (Outputs 3 and 7).

2.2.5 Projected potential impact

The aim is to reach a total of approximately 30 schools and 3000 children within the four target areas in South Africa, if the current activities are continued during the next two years.

2.3 Birds as bio-indicators of impact of land-use in arid rangelands

Desertification, whether due to anthropogenic pressures, climate change or other factors, has become a global concern. The far reaching effects of desertification have prompted the formation of the United Nations Convention for the Control of Desertification (UNCCD) and the initiation of the Desert Margins Program (DMP) in order to attempt to control desertification. This study formed part of the first phase of the DMP, but refinement and implementation of the use of birds as bio-indicators is continued in the 2nd phase.

2.3.1 The basis of the technology's success

The results showed a definite decline in bird species diversity with an increase in land degradation, especially due to the simplification of the vegetation structure because of grazing. Both bird species diversity and the number of birds declined with the increase in land degradation. The guild analysis showed that although the actual number of species occurring at the various sites changed, aggregations remained relatively similar with regard to feeding guilds. At all the sites, analysis of feeding guilds showed that insectivores were the guild's most represented, with granivores second most and then a variation in other guilds at each site. Breeding guilds showed a much greater variation in percentage composition of the guilds. At sites with less shrub and tree strata, ground nesting species were better represented, whereas the sites with a better developed tree and shrub strata had a greater occurrence of tree nesting birds than the other guilds. The deduction to be made from this is that bird species composition changes can be attributed to their nesting needs to a much greater extent than their feeding needs.

Bird species varied in their response to changes in the vegetation structure at different sites with specialist species, such as raptors and specialist insectivores being more vulnerable to changes in vegetation structure than generalist species, such as granivores and generalist insectivores. It was shown that vegetation structure played the most important role in determining species diversity, in the Molopo district of the North-West Province. Bird diversity has also been shown by this study to be a cost effective, easy way of determining the degree of degradation, as well as a possible tool for monitoring the effectiveness of restoration.

2.3.2 How is it implemented?

Four sites were chosen to represent different degrees of degradation. Vegetation structure analyses were carried out at each of the sites in order to determine the degree of change brought about by land use. The birds at each of these sites were surveyed using transects. Surveys were repeated over four seasons to give some indication of the effects of seasonality on bird populations of the different sites. Statistical analysis was carried out.

Bird diversity as indicator of land use will be communicated through the development of Common Language Indicators (CLI) to communities, such as schools, farmer groups, and conservation authorities through pamphlets and presentations. The Endangered Wildlife Trust is a partner in this endeavor with advice on communication. This aspect is and lessons learned as well as CLI will being developed be implemented in Phase 3.

2.3.3 Up-scaling the technology

This technology is applicable to all areas with savannah-like vegetation but should be adaptable to other vegetation structures as well. It is therefore scale-neutral for savannahs and can be implemented where required. At present, we are only up-scaling in the Molopo region. Further up-scaling will require additional funding and time. It can definitely be applied in other countries, for which new partners will have to be identified.

2.3.4 Contribution to the overall DMP project goal and objectives

This technology specifically contributes to improved understanding of ecosystem and dynamics with regard to loss of biodiversity (Output 1), development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems, enhancing the capacity of stakeholders (Output 3) and implementation of participatory natural resources management (Output 6). Reports are available for most of these, but other aspects are still being developed or are being tested.

2.3.5 Projected potential impact

This project is mainly aimed at protecting existing biodiversity and improving bio-diversity in impacted areas through local empowerment (CLI). Four areas have been targeted in the Molopo region, and to date about 50 farmers and 1700 pupils have been reached.

B. Botswana

1. The context

Botswana is a semi-arid country and water is often in short supply. However low rainfall does not mean low levels of soil erosion by water as much of the rainfall comes through thunderstorms of high intensity and erosive power. When these rains do come, there is often poor protective vegetative cover. Reduction of soil fertility by soil erosion leads to low crop yields. This type of land degradation is particularly common in the hardveld of eastern Botswana where Bobirwa sub-district, a DMP target area, is located. The challenge is how to effectively control soil erosion.

Pastoralists of the communal rangelands of Botswana mainly perceive their worst problems as being drought and inadequate number of livestock. Most of them try to promote rapid increase of their livestock between droughts as a way of compensating for low productivity per animal due to limited grazing area. Besides, the primary aims of security of livestock assets and subsistence encourage having a high number of livestock. As a result, livestock and rangeland conditions are particularly poor during drought periods and the farming communities are equally adversely affected. However, there are mechanisms they can be used to deal with lowered productivity of rangeland and to alleviate its impact on sustainable development. Techniques that lessen the impact of drought are more effective if they provide early warning to resource users of possible unfavorable rangeland conditions. Continuous monitoring and observation of existing rangeland conditions are essential to be able to detect any patterns or trends towards a decline in agricultural or ecological activity. The challenge is how to empower the communities to monitor and observe the environment around them.

Although agriculture is still the mainstay of the rural economy in Botswana, there are other activities undertaken in the rural areas, which supplement the income of the rural dwellers. These activities, which are undertaken together with agricultural activities, include harvesting of forest products, trading and beer brewing, in order of importance. In Bobirwa sub district (hardveld), non-agricultural activities that are sources of income include the harvesting of phane caterpillar (*Imbrosia belina*) and mokolwane (*Hyphaene petersiana,* palm tree). Although phane and mokolwane are potential sources of income for rural dwellers, the majority do not exploit these resources for commercial purposes. In Kgalagadi district (sandveld), there is commercial harvesting of forest products especially sengaparile (*Harpagophytum procumbens*, grapple plant) and mahupu (*Terfezia pfellii*, Kalahari truffle) by remote area dwellers (RADs). In both eco-regions, harvesting of forest products is carried out under open access regime. Thus, everyone is free to harvest the forest product phane without any limitation as to quantity and harvesting methods used. Open access resources are prone to over harvesting since the benefits accrue to individual harvesters, while the costs in terms of damage to the resource is borne by all. Among factors that inhibit rural dwellers from engaging in commercial harvesting of forest products is lack of coordinated marketing systems for the products. For example, phane harvesters do not have proper markets to sell their produce, and instead mainly rely on people who come to buy from harvest sites. Moreover, most of these forest products are sold after very little processing. For example, phane is sold dried without any processing. Thus, there is little value addition taking place. The challenge is, therefore, to find ways in which rural communities can sustain livelihoods through harvesting and processing of forest products, and marketing of value-added end products.

2. Description of the technology/strategy

Mechanical erosion control is the physical control of soil and water movement by the use of drains and terraces. It is being applied in Bobirwa sub district and other districts in the hardveld to reduce the velocity of water and safely dispose of excess water. The three basic components of mechanical erosion control being applied are:

- The cut off drain which diverts storm runoff originating from the uncultivated land above the field;
- The graded contour ridges leading away the runoff from cultivated land;
- The grass waterway into which both the cut off drains and graded contour ridges discharge, and which allows the excess water to drain safely away from the field to a natural depression or stream.

2.1 Mechanical erosion control

2.1.1 The basis of the technology's success

Simple designs of mechanical erosion control components are provided by the agricultural extension service staff, who also assist the farmers in staking out the control structures. The farmers construct cut off drains and graded contour ridges in their own fields. If waterways are expected to be large, construction assistance is sought from the agricultural extension service. On gentle slopes, farmers are encouraged to cultivate on the contour (ie, contour ploughing) and to use grass strips to slow the velocity of water and trap sediment. The mechanical erosion control measures appear to be working well for the hardveld soils, which are predominantly loams to sandy clay loams.

2.1.2 How is it implemented?

Currently, mechanical erosion control is effected on 12,000 ha of cultivated fields. Implementation of mechanical erosion control is carried out under the auspices of the Forum for Integrated Resource Management (FIRM) participatory approach. The technology is included in the integrated work plans of Mathathane village. FIRM encompasses all important stakeholders and partners, including the communities themselves, government departments, village development committee (VDC) and local institutions.

2.1.3 Up-scaling the technology

The initial focal point for up-scaling is Mathathane village. Thereafter, other major villages in Bobirwa sub district, that is, Tsetsebjwe and Motlhabaneng, will be brought into the fold. Mechanical erosion control measures can be applied in other countries where the climatic and soil regimes are similar to those of the hardveld. The agricultural extension service of the Ministry of Agriculture will be of great assistance in the up-scaling phase.

2.1.4 Contribution to the overall DMP project goal and objectives

This technology, if fully implemented, contributes to the specific objective of developing and implementing strategies for conservation, restoration and sustainable use of dryland biodiversity (Output 2).

2.1.5 Projected potential impact

The projected potential impact of this technology is to reduce land degradation by putting more than 48,000 ha of potentially erodible arable land under effective mechanical erosion control.

2.2 Local level monitoring (LLM)

Local level monitoring (LLM) is a tool that can be used directly by farmers to collect information on important indicators so that they can make timely management decisions and thus better manage their natural resources. The four relevant indicators of rangeland conditions are livestock condition, fodder availability/carrying capacity, rainfall, veld condition and bush density.

Local monitoring programs focus on the regular and continued observation and assessment of conditions of the four indicators over time by the resource users. Communities themselves identify information needs, and in close cooperation with technical advisors, develop relevant indicators for rangeland conditions for monitoring purposes. A field guide developed in Namibia on how to conduct regular monitoring, with color photos, graphics, color coded information sheets, charts and guidelines will be used by farmers/pastoralists of Bobirwa sub district and Kgalagadi district to assess rangeland conditions.

2.2.1 The basis of the technology's success

The LLM approach is most likely to be successful in Botswana because the open access rangeland conditions are similar to those of Namibia where the tool was developed.

2.2.2 How is it implemented?

Implementation of the LLM tool will be effected under the auspices of FIRM. Pastoralists, government departments and VDCs are important players for the successful implementation of the LLM tool in the target districts. The LLM tool will be tested initially at Tshane and Maubelo villages of Kgalagadi district, and at Mathathane village of Bobirwa sub district, before spreading out to other villages of the two target districts.

2.2.3 Up-scaling the technology

The LLM tool can be applied to other countries with similar rangeland conditions to those of Botswana and Namibia. Agricultural extension service (Animal Production) personnel will be of great assistance in the up-scaling phase.

2.2.4 Contribution to the overall DMP project goal and objectives

The application of LLM tool by the communities will contribute to the specific objective of developing and implementing strategies for conservation, restoration and sustainable use of dryland biodiversity (Output 2) through capacity building.

2.2.5 Projected potential impact

The projected potential impact of this tool is to manage the environment and the natural resources in a sustainable manner by putting at least 50,000 ha of rangeland under stable ecosystem use.

C. Namibia

1. The context

Namibia is the most arid country in sub-Saharan Africa with naturally low agricultural productivity. Rainfall is low and highly variable with the occurrence of drought as a natural phenomenon. Coping with dry periods is therefore a way of life for the almost 80% of the population that are largely dependent on this very vulnerable natural resource base. The impact of drought, rangeland degradation, biodiversity loss, land degradation and reduced agro-pastoral productivity are common phenomena in rural farming communities in Namibia.

The eastern communal lands (DMP study area in Namibia) receive between 380 and 480 mm of summer rain annually. The block of communal land that forms the eastern communal areas covers about 76,800 square kilometers, with its eastern border the international boundary with Botswana. The area has only 2.6% of Namibia's population, 9.3% of its area and 12% of its cattle. All land in the region is communal by the terms of the Communal Land Reform Act of 2002, and as a result formally owned by government. Communal Land Boards are being established in the region to exercise control over the land. Freehold ownership of communal land is not possible. Okamatapati and Rietfontein have large blocks of surveyed and fenced farms. The sizes of farms in both blocks ranges between 4000 and 6000 ha. Together, both blocks cover 8,800 sq km or 17% of the area.

Most of the study area is covered by relatively homogeneous sands of the Kalahari Basin, with only some erosion plains of the Central Plateau in the far western portions. The far southeastern corner (Rietfontein area) has some sub out cropping rocks. Most soils belong to the arenosols (deep sands) of the Kalahari Basin. These are mostly with poor horizon development due to the arid environment. It is only in the drainage lines (*omiramba*) and in the areas with sub outcropping that geological formations soils with a more distinct horizon development have been found, mainly calcisols and fluvisols. The sandy landscapes of the Kalahari system are generally flat to rolling: plains incised by *omiramba* valleys or alternated with fossil (no longer moving) sand dunes. The most widespread vegetation type is the *Terminalia sericea – Combretum collinum* shrubland, covering roughly 80% of the study area. Three major natural resources land, water and cattle stand out as having much more value than any other in the study area. Their use and management (or lack thereof) has important consequences for the future of the people and the environment.

Communal farmers have little or no influence on major environmental, physical, economic or policy factors affecting their livelihoods. There are however mechanisms that they can use to deal with reduced productivity of rangelands and to mitigate adverse impacts on their livelihoods. Continuous monitoring and observation of existing rangeland conditions is essential to detect any patterns or trends towards a decline in agricultural or ecological activity. Easily recognizable and usable indicators are needed that provide farmers with relevant and timely information about their rangeland and its productivity.

2. Description of the technology/strategy

Most methods being promoted for land use management are too scientific, time consuming and sometimes too complicated to meet the needs of farmers. Very often, information is collected by farmers but very little is done to use that data to make informed management decisions. This defeats the purpose of monitoring and very often leads to a loss of motivation among farmers to continue with the monitoring system. It was against this background that the Desert Margins Program (DMP) built on existing experiences in Namibia's Program to Combat Desertification (Napcod) and developed and tested an easy and practical Local Level Monitoring (LLM) system for use by livestock farmers in the eastern communal lands of Namibia and other places.

2.1 Local Level Monitoring

2.1.1 The basis of the technology's success

Building on past experiences from Napcod, DMP Namibia developed and tested an easy and practical LLM system for use by livestock farmers in the eastern communal lands of Namibia and other places. The LLM method is based on the development and application of a series of field guides using certain indicators. These indicators are livestock condition, fodder availability, veld condition and changes in bush density, and rainfall.

Livestock condition reflects to a large extent, the condition and productivity of the veld that animals are feeding on. A photo guide depicting five different livestock condition classes has been developed. These five condition classes vary from very lean, lean, moderate, fat to extremely fat. On a monthly basis, farmers then score a representative sample of their herd by comparing actual livestock condition to the closest condition class in the photo guide. Fodder availability provides an indication of the number of livestock a given piece of land in a specific area is able to sustain for a specific period of time. This is closely related to the availability of fodder that is in turn closely related to rainfall and management impact. A photo field guide is developed for visual assessment of fodder availability on a monthly basis. This field guide is area specific and includes a series of photographs depicting various amounts of fodder available. These photographs range from veld with very little fodder to veld with a lot of herbaceous material. Veld condition reflects the current condition of any piece of land and focuses on species composition of the herbaceous layer, density, vigor and soil condition and fertility. A number of fixed-point photographs are taken on the farm to develop a photo guide for assessment of veld condition. These permanent points are visited annually, usually at the end of the rainy season, and the current veld condition is compared to the condition of the same site on the photograph. The same picture guide developed to detect changes in veld condition can be used to monitor changes in bush density and structure.

The LLM method is not designed to give an exact account of changes in the different parameters, but rather to be used by farmers as a tool for debate and improved decision making at the grassroots level.

Table 2. Progress of implementation of local level monitoring systems in Namibia.

Localities	Indicators introduced	Indicators being implemented	Introduced by	Ongoing support by
North west				
Dawib Wes, Okombahe	1, 2, 3, 4	1, 2, 4	FIRM/Napcod	DEES
Grootberg Communal Area	1, 2, 3, 4	1, 2, 4	Napcod	DEES; DRFN
Grootberg Emerging Farmers	1, 2, 3, 4	1, 2, 4	DEES	DEES; DRFN
Khorixas Extension Services	1, 2,3, 4	-	Napcod	No follow-up
Okamapuku	1, 2, 3, 4	1, 2, 4	Napcod	DEES
Soris-soris Conservancy	1, 2, 3, 4 to DEES & community	-	Napcod	No follow-up
West				
Kuiseb basin	1, 2, 3, 4	-	Elak	None
North				
Onkani	1, 2, 4	2	Napcod	Individual OLDeP staff member
Oshikoto (9 CBOs & AETs)	1, 2, 3, 4 for DEES only to date 40 farmers trained		OLDeP	OLDeP; DEES
South				
Hoachanas Area – Blankenese	1, 2, 3, 4	-	Napcod	Limited follow-up by DEES
Nico-Nord	1, 2, 3, 4	2, 3	Napcod	Limited follow-up by DEES
Oskop	1, 2, 3, 4	-	Napcod	Limited follow-up by DEES
Tsub-gaub	1, 2, 3, 4	-	Napcod	Limited follow-up by DEES
East				
Coblenz	1, 2, 4	1, 2, 4	DMP	DMP, DEES
Okakarara	1, 2, 4	1, 2, 4	DMP	DMP, DEES
Okamatapati	1, 2, 4	1, 2, 4	DMP	DMP, DEES
Okanjatu	1, 2, 4	1, 2, 4	DMP	DMP, DEES
Otjituuo	1, 2, 4	1, 2, 4	DMP	DMP, DEES

1 = Livestock condition, 2 = Rainfall, 3 = Rangeland condition and bush density, 4 = Fodder availability. AET = Agricultural Extension Technician, CBO = Community Based Organization, DEES = Directorate of Extension and Engineering services, DMP = Desert Margins Program, DRFN = Desert Research Foundation of Namibia, Elak = Environmental Learning and Action in the Kuiseb, OLDeP = Oshikoto Livestock Development Project.

2.1.2 How is it implemented?

Napcod initially developed local level monitoring in four pilot communities, Grootberg in north western Namibia, Omatjete in western Namibia, Onkani in north central Namibia, and Gibeon in southern Namibia (Figure 2). However, after the system was tested in these areas, other stakeholders such as the government's extension services, CBOs and NGOs in Namibia wanted to use the same tool in other parts of the country. Presently the LLM system has been introduced and is being implemented at various levels in seven areas throughout Namibia (Figure 2 and Table 2).

2.1.3 Up-scaling the technology

The LLM system was initially developed and implemented at four Napcod pilot sites. However, the system has been adopted by other stakeholders, ie, government extension services, CBOs and NGOs. The progress of the implementation of these different initiatives is summarized in Table 2.

As can be seen in Table 2, the level of success of the implementation differs considerably between the different sites. The reason for the limited success of the implementation of LLM in the northern Napcod pilot area is most likely due to the lack of back stopping and support. Furthermore there was no support from extension services in the area after Napcod came to an end.

2.1.4 Contribution to the overall DMP project goal and objectives

The application of the LLM tool by the communities will contribute to the specific objective of developing and implementing strategies for conservation, restoration and sustainable use of dryland biodiversity (Output 2) through capacity building.

2.1.5 Projected potential impact

The projected potential impact of this tool is to manage the environment and the natural resources in a sustainable manner. Implementing this technology will also support farmers to make pro-active decisions in order to reduce their vulnerability to drought and seasonal variability in rainfall. In general it seems that farmers prefer to carry out monitoring of rainfall and assess the condition of livestock instead of assessing rangeland condition or fodder availability.

2.2 The Forum for Integrated Resource Management (FIRM)

The Forum for Integrated Resource Management (FIRM) can best be described as an approach to ensure that rural farmers living on communally managed farmlands are in charge of their own development. It involves a community based organization (CBO) 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 or private extension services, non governmental organizations (NGOs), other CBOs with short or long term projects.

2.2.1 The basis of the technology's success

The key element of the FIRM approach is the collaborative planning, implementation and monitoring process led by the CBO representing the community involved. This usually takes the form of an annual meeting to which all CBO members and associated service providers are invited. During this facilitated meeting, the goals and objectives of the community are reviewed and reaffirmed or revised. Results obtained from formal or informal monitoring of the previous year's plans and activities are then thoroughly discussed and lessons learnt are extracted. This analysis serves as the basis for the next, key step of the annual meeting, operational planning for the coming year. During this process, the various service providers commit themselves to providing specific support to the community based organization on the community's own agreed-upon objectives. This approach ensures that the services provided by mandated service providers and project partners are in line with the needs and wishes of the CBO and the greater community.

2.2.2 How is it implemented?

The FIRM approach was first established in collaboration with the Grootberg Farmers' Union (GFU) and soon thereafter expanded to overlap with the Khoadi/Hôas Wildlife Conservancy. This farmers' organization was recognized to be one of the better organized associations with the infrastructure of an agricultural research station ceded to them from the government. At the time the FIRM approach was initiated, four independently-funded national development projects as well as numerous other service providers were active in the area. The FIRM was established to help the four development projects coordinate their support to the already well organized and active CBO.

2.2.3 Up-scaling the technology

FIRMs in six different areas of Namibia are examined to review their progress, implementation and effectiveness. These six areas, the projects with which they are/were associated and their primary agriculture focus are summarized in Table 3 and Figure 3.

Table 3. Areas of selected FIRMs, the projects that support them and the primary focus of their activities

Area	Projects	Primary focus
Grootberg, Kunene region	Sardep, Napcod, Caws (GTZ)	Rangeland, large and small stock; wildlife
Onkani, Omusati region	Sardep, Napcod (GTZ)	Rangeland, large stock and small stock
Gibeon, Hardap region	Sardep, Napcod (GTZ); Ephemeral River Basins (Norway)	Rangeland, small stock and water management
Kuiseb, Erongo region	ELAK (EU)	Small stock and water
Okakarara, Otjozondjupa and Omaheke regions	DMP-GEF	Large and small stock
Oshikoto region	OLDeP, NASSP (EU)	Large and small stock; livestock marketing

Sardep = Sustainable Animal and Range Development Program; Napcod = Namibia's Program to Combat Desertification; Caws = Communal Area Water Supply Project; ELAK = Environmental Learning and Action in the Kuiseb; DMP-GEF = Desert Margins Program (Global Environment Facility); OLDeP = Oshikoto Livestock Development Project; NASSP = National Agricultural Support Services Program.

Analysis of the six selected FIRMs revealed very different states of progress in terms of the overall objectives of their establishment. The six FIRMs that are currently actively pursuing activities all undertake some form of annual planning and ongoing monitoring of activities of the CBO and their service providers. As the current partners of the FIRMs come from different origins, their approaches and their activities vary.

The major prerequisite is that local resource users (eg, farmers) be in charge of the process and that it is not steered by influential local service providers. The composition of the FIRM is determined by the objectives and priorities of that specific CBO that leads it and can vary considerably from year to year. The FIRM approach depends heavily on external financial support and efficient extension services for it to be successful. In all cases referred to in Table 4, strong externally-funded support programs played a major role in getting the FIRM off the ground and supporting its activities. A major challenge is to ensure institutional sustainability of these organizations after the end of the externally supported initiative.

The FIRM approach has been identified and adopted by the Directorate of Extension and Engineering Services of the Ministry of Agriculture, Water and Forestry (MAWF) as parallel to and supporting their Farming Systems Research and Extension (FSRE) approach. The MAWF is currently enhancing the various forums within which they operate. Although the FIRM is seen as meetings only to some observers, it has proven to be useful where direct interaction between local communities and service providers take place.

Table 4. Six selected FIRMs, their current activities and development partners with comments on their current status.			
Area	**Current activities**	**Current partners**	**Comments**
Grootberg, Kunene region	Tourism and wildlife management, local level monitoring, livestock husbandry	Government extension services including DEES, DVS, DRWS; #Khoadi //Hoas Conservancy; LIFE project; NNF	This is the oldest FIRM and is currently used as demonstration site for most newly established FIRMs
Onkani, Omusati region	Community development, livestock health, natural resource management	DEES; DVS; independent researchers	Also one of the earlier FIRMs and used as demonstration site for new FIRMs in the northern communal areas
Gibeon, Hardap region	Community development, natural resource management, small stock farming	ERB	The Gruendorner Farmers' Association is a very strong local cooperative that drives this process
Kuiseb, Erongo region	Water management, livestock farming	DEES; DRWS	The Kuiseb River Basin Committee adopted the FIRM approach to suit their objectives
Okakarara, Otjozondjupa and Omaheke regions	Livestock farming, rangeland management, community development	DMP	The Local Development Committees (LDCs) that are decentralized structures of the regional government adopted this approach
Oshikoto region	Livestock farming, livestock marketing, rangeland management, water management	OLDeP	These are the latest FIRMs and are being coordinated in nine constituencies within the Oshikoto region

DEES = Directorate Extension and Engineering Services; DVS = Directorate Veterinary Services; DRWS = Directorate Rural Water Supply; Life = Living in a Finite Environment; NNF = Namibia Nature Foundation; ERB = Ephemeral River Basin project (Government of Norway); DMP-GEF = Desert Margins Project (Global Environmental Facility through UNEP and ICRISAT); OLDeP = Oshikoto Livestock Development Project; FIRM = Forum for Integrated Resource Management

2.2.4 Contribution to the overall DMP project goal and objectives

This technology contributes directly to capacity building of the stakeholders (Output 3) and participation of stakeholders in project implementation (Output 7).

2.2.5 Projected potential impact

This technology has a great potential in building the capacity of the local communities thereby empowering them to better manage their natural resources.

D. Zimbabwe

1. The context

The DMP project is being implemented in the three provinces of Matebeleland North (Tsholotsho district), Matebeleland South (Matobo district) and Masvingo (Chivi district) that occupy some of the driest areas in the country. The project is striving to impart a human–natural resource interaction, while providing for the livelihood of the rural communities ensuring restoration and sustainable management of the natural resource base and a rich bio-diversity. A wide range of institutions and organizations that are concerned with sustainable land productivity and improved livelihoods have participated in the design of the Zimbabwean project and are currently involved in its implementation.

The characterization processes (Phase 1) culminated in priority lists of challenges and opportunities for each site. Through participatory and consultative approaches, different stakeholders and partners in all the three sites used these priority lists to design interventions for implementation. Participants were also accorded the opportunity to compare emerging issues among the three sites at this formative stage. The consolidated list of challenges and opportunities shown in Table 5 consists of those selected for intervention.

Table 5. Zimbabwe: The problem context and rationales.

Key problem	Key manifestations	Effects
Bio-physical: Land degradation	Loss of bio-diversity: Key species of trees, grasses & animals no longer available. Vast areas are deforested due to frequent bush fires, massive tree cutting for curios, firewood and opening for arable plots. Land pressure has resulted in households settling in grazing areas further reducing grazing areas.	Current: Low diversification within fauna and flora, increased erosion of biodiversity and reduced livelihood options from natural bio-resources. Future: Continued degradation expected if nothing is done to reverse these processes.
	Soil erosion & gully formation: Deforestation and vast areas of bare land have resulted in serious soil losses and gully formation especially in the grazing areas and valley sides where unprotected arable plots were opened. The result has been the development of deep gullies and siltation of rivers, dams and wetlands.	Current: Massive losses of soil and nutrients have reduced productive capacity of environs. Future: Increased poverty and food insecurity if nothing is done.
	Poor rangeland productivity: Land degradation has resulted in poor rangeland productivity, and reduced grazing land has also caused overgrazing as livestock are kept on small pieces of land over long periods of time. This has added to land degradation through soil loss and the formation of gullies through continuous trampling. Due to reduced rangelands, livestock graze along rivers, valleys, wetlands and fallow arable plots. These areas are continuously reducing in productivity due to bush encroachment and proliferation of hard and unpalatable grasses.	Current: Lack of dry season feed resources, leading to poor animal health, productivity and high mortality. This has overall negative effects on household incomes and reduces potential for food production through lack of draft power in the cropping season as animals will tend to be weak. Future: Increased poverty and hunger.

Key problem	Key manifestations	Effects
	Drying up & siltation of wetlands: Numerous wetlands have been negatively affected by cattle trampling and overgrazing, whilst others have been poorly utilized without protection. Most of these wetlands have lost their functions and are now dissected with gullies that are covered with sand and silt eroded from catchment areas. Water tables are lower, and ponds and pools have disappeared together with all life forms associated with such ecosystems. The habitat changes have also affected wetland plant and animal species that benefited communities by providing medicines, fruits, materials for craft, thatch, animal feed, protein, etc. Wetlands (*Dambos*) provided natural water harvesting systems on which soil moisture remains for longer periods long after rains and this formed strategic food production zones even in droughty seasons.	Current: Drying up of wetlands means lack of surface water in the dry season, and this means reduced capacity of households to produce crops in the dry season, and loss of dry season grazing as some of the wetlands were used as key dry season feed sources. Domestic water supplies, animal watering, game hunting, fruit gathering, etc have also been lost and thereby increasing food insecurity, poverty and alternative livelihoods options.
	Poor soils: The pilot area in Chivi has sandy loams that are inherently poor. These soils have been cultivated for decades and have not been allowed time for regeneration. Lack of fertility management technologies have resulted in soil mining, further reducing the productivity potential of the soils. Lack of protection of the soils through construction of conservation structures (contours) has further reduced the productivity of the soils as most of the arable plots are located on sloppy valley sides. Although the soils and the erratic rainfall regimes are not suitable for maize production, farmers insist on production of the staple maize crop despite poor yields.	Current: Low yield levels production per hectare due to poor soils and mid-season droughts, leading to poor food security at household level year after year. Future: Degradation (soil loss, decreasing soil fertility, acidity, etc) continues and livelihood decline will ensue if not attended to.
Socioeconomic conditions	Limited livelihoods options: Rural livelihoods in the pilot areas are dependent on agriculture and natural resources. There are limited options for farmers outside agriculture and natural resources. There is however room for improvement through value addition and venturing into agro-processing of the locally available produce and resources.	Current: Household incomes remain low as excess produce in its raw form, leading to low beneficiation by the farmers compared to the potentials associated with value addition.
	Community capacity: Communities have limited financial, technical and management capacity to drive local development.	
	Farmers' access to agricultural inputs: Agricultural inputs are a major challenge to farmers. These include appropriate seeds (especially high yielding small grains and legumes) and fertilizers for cropping purposes. In the livestock sector, there are challenges with the availability of dry season feed resources such as manufactured feed supplements, vaccines and other medicines for disease control.	
	Farmers' access to markets: Farmers' access to competitive markets is a major challenge. Where households produce excess crops, their access to markets is limited, resulting in farmers selling to middlemen who offer lower prices for the products, especially livestock, Mopane worms and some cash crops.	
Policy, Environment	Poor knowledge of existing policies: Local level institutions and farmer groups have poor knowledge and understanding of the current policy environment. This leads to lack of the communities' use of policies meant to guarantee their access to resources and the related benefits. This is particularly so in relation to wildlife resources in Matobo and Tsholotsho.	Current: Potential benefits are not being received by the communities, especially on the control and use of resources such as grazing, wildlife and wetlands. Future: As poverty increases so will degradation of natural resources

Key problem	Key manifestations	Effects
	Inadequate policy frameworks: There are inadequate policy frameworks especially to do with the issues of access to water and the management of water resources. The National Water Authority has a mandate to charge for the use of water from all water sources including ground water and water from rivers. It however does not provide for the management of catchments and other water infrastructure such as dams. This has created a gap in the management of catchments and dams. This has become evident in the Gariya project in Tsholotsho. Policies are generally not designed with the promotion of "efficient use of water in focus".	Current: There is lack of systematic maintenance of dams and related infrastructure, leading to the collapse and breaching of dams especially in Tsholotsho. Lack of systematic provision of resources for catchment management has led to uncontrolled erosion and siltation of dams and rivers in the three sites. Future: Continuing trends can result in major conflicts over water.
	Local institutional capacity issues: Local level institutions do not have the capacity to implement and enforce policies on natural resources. The new Environmental Management Act has not been taken to the local level institutions, and in some cases (Tsholotsho & Chivi) the relevant institutions have not been put into place. Therefore policy implementation remains a challenge as the institutions are not in place and where they are in place, they are not adequately equipped to implement their roles according to available policy frameworks.	Current: Local institutions have limited capacity to engage public/private sector institutions for the redressing of problems related to environmental management and use.

2. Description of the technology/strategy

Table 6. Selection of technologies/strategies to effect change

Key problem	Key manifestations	Technology of choice	Pilot site	Strategy
Bio-physical: Land degradation	Loss of bio-diversity	Reintroduction of extinct grass & tree species, enrichment planting, woodlots, woodland management. Enhancing value of natural resources/ecosystems by improving benefit from the same and thereby raising incentives and appreciation by communities.	Matobo, Tsholotsho	Community capacity building, Farmer Field Schools (FFS), demonstrations, use of national tree planting events, botanic gardens, universities, etc.
	Soil erosion & gully formation	Catchment & woodland management, land rehabilitation, gully reclamation using gabion structures, silt traps and vertiver grass. Conservation measures including level contours, infiltration pits vegetative cover. Partnerships have been formed with private sector, public sector and technical departments.	Matobo, Tsholotsho, Chivi	FFS, demonstrations, policy review, encouragement/enforcement and highlighting cause and effect in training and demonstrations.
	Poor rangeland productivity	Enrichment planting, introduction of legumes, planted forages (Bana grass & Luceana), control of bush encroachment, grazing management (65000 ha).	Matobo, Tsholotsho, Chivi	Training through FFS, demonstrations and enhancing resource value, community participation and ownership.

Key problem	Key manifestations	Technology of choice	Pilot site	Strategy
	Poor dry season feed resources	Urea treatment of crop residues, use of acacia pods, planted forages, hay bailing.	Matobo, Tsholotsho, Chivi	FFS, demos and partnerships with Care and Heifer International and commercial farmers.
	Drying up & siltation of wetlands	Catchment management, control of livestock movement through fencing or herding, sustainable use of wetlands using the *Ngwarati Cultivation System*.	Chivi	FFS, demos, and partnerships with Care and Heifer International.
	Poor soils and crop yields	Use of soil amendments such as termitaria, use of inorganic fertilizers in micro-dosing, conservation agriculture, use of organic fertilizers. Use of short season varieties and small grains. Crop management techniques.	Chivi, Tsholotsho	FFS, demos
Socioeconomic conditions	Limited livelihoods options	Value addition in the way of processing Mopane worms, wetland use in Chivi and micro-irrigation particularly in Tsholotsho.	Matobo, Chivi, Tsholotsho	Research into potential Mopane worm products. Adoption of improved wetland use systems.
	Community capacity	Capacity building of community institutions namely traditional leaders and the natural resources committees. Capacity building of change agents such as extension and NGOs.	Matobo, Tsholotsho, Chivi	Community workshops, tailor-made training, exchange visits.
	Farmers' access to agricultural inputs	Facilitate establishment of grassroots clubs/groups and link with credit providers	Matobo, Tsholotsho, Chivi	FFS, community workshops, credit facilities identification and linking.
	Farmers' access to markets	Farmer education and linkages to markets for different products including livestock, Mopane worms, crops, etc.	Matobo, Tsholotsho, Chivi	FFS, community workshops, marketing facilities identification and linking.
Policy, Environment	Poor knowledge of existing policies and policy processes	Community capacity building through various engagement levels.	Tsholotsho, Matobo	FFS, distribution of literature on relevant policies, training.
	Inadequate policy frameworks	Policy advocacy engaged through support with GEFSGP	Matobo, Tsholotsho, Chivi	FFS, community meetings with policy makers and implementers.
	Local institutional capacity issues	Training of natural resources committee.	Matobo, Tsholotsho, Chivi	Participatory engagement/training, exchange visits.

2.1 Various technologies to address land degradation problem in Zimbabwe

2.1.1 The basis of the technology's success

Table 6 shows a number of technologies that have been selected and implemented in the different environments within the three pilot sites of DMP-Zimbabwe. Most of these technologies have been tested over time at research stations, in on-farm trials and verified by participating farmers even before the initiation of DMP. What has been missing for most of these technologies and approaches has been their interfacing with farmers, who see the opportunity and are supported in its adoption beyond mere introduction. For the target communities in DMP the need is obvious and the opportunities and benefits are evident to the level that they do not necessarily need statistical verification. The approaches used in raising awareness, identifying problems, prioritizing issues and selecting options as solutions has empowered the communities to single out those that they can invest their energies in.

2.1.2 How is it implemented?

A number of implementation strategies were employed as some of the technologies were once implemented in the past though with limited success in some cases. The aspects of the strategies included the following:

• The demand driven approach
This was employed on some technologies that had been introduced through a number of farming programs. These include technologies that have direct impact on household benefits/incomes or capacity to produce adequate food. These are technologies that enhance crop production such as tied ridges, land reclamation, improved varieties, small grains, crop management and use of soil amendments and inorganic fertilizers. On the livestock front, this included knowledge and techniques on disease control, dry season feed production and general herd management.

• Demonstrations
Demonstrations were done through FFS based on farmer choices and only on those issues emerging as promising from on-farm testing and verification. These are simple and with easily discernable effects. Exchange visits to sites and communities with technologies already at work will play a significant role. This is drawn from the experience which has shown that learning through seeing and peer interaction is very powerful.

2.1.3 Up-scaling the technology

A number of strategies were identified for up-scaling of technologies:

• Intensification
The technology application and adoption started with a few farmers in one geographical area. As results demonstrate, more farmers in the same area started to learn, apply and adopt the technology as the normal way of doing things. In other words, more farmers in one area apply the technology from seeing results from other more successful farmers.

• Expansion
This involves coverage of farmers from a bigger geographical area than covered by the pilot. This will be done first across the current pilot sites and then to adjoining areas that have similar conditions.

• Promotions
These will be done through learning visits and seed fairs where farmer-to-farmer learning will be emphasized. Where farmer networks are strong, trained farmers will help train other farmers that are interested in the new technology.

The technologies enumerated in Table 6 will be disseminated to other sites in the country based on the criteria of nearness to the current sites, demand by farmers, areas covered by the current partners and target areas by potential donors. Up-scaling of current technologies will follow such areas such as the San inhabited areas in Tsholotsho, the Matobo Hills World Heritage site and the Great Zimbabwe National Park. These technologies can also be up-scaled to other countries. Key partners for up-scaling these technologies include local communities, research institutions, extension services and other relevant government institutions and NGOs.

2.1.4 Contribution to the overall DMP project goal and objectives

The technologies being implemented in the project sites aim at the conservation and restoration of biodiversity in Desert Margins through sustainable utilization of resources. These technologies address project Output 2 (strategies for conservation, restoration and sustainable use of degraded agro-ecosystems), Output 3 (capacity building of stakeholders), Output 4 (sustainable alternative livelihoods) and Output 7 (stakeholders' participation).

2.1.5 Projected potential impacts

When implemented to completion the various components being attended to within the program will have accumulated effect to achieve the following impacts:

- Increased biodiversity particularly in the rangelands that will then be under improved management in respect to rotational grazing, reduced fire damage, less tree felling, reduced erosion and generally better appreciated due to a better and more informed perspective in respect to their value. Matobo District alone is expected to have more than 65000 ha of rangelands influenced. Tsholotsho will have more than this as it also covers wildlife areas.
- Households in participating communities will have more income from the marketing of goods and products drawn from forests and woodlands (timber and non-timber) and rangelands (livestock). The organized Mopane worm marketing enterprise is expected to generate huge returns for the communities. Improved management of wetlands and their related catchments in Chivi District is expected to bring about increased production capacities of these environments. Micro-irrigation schemes to be established in Tsholotsho feeding from the Gariya Dam water is expected to improve nutrition and reduce food shortages particularly amongst the Sani communities. The canalized water from the dam to both game and livestock areas will bring about reduced degradation and less crop damage from roaming game that will then have no impulse to roam into human settlements as they currently do in search of water.
- Conservation works in arable areas within uplands will enhance soil water retention and hence their adoption is expected to improve crop yields and this will be augmented with the introduction and use of stress tolerant varieties.

E. Kenya

1. The context

The problem of desertification and land degradation in Kenya presents a major threat to all facets of land productivity. The potential scale of desertification in Kenya is serious as over 80% of the total land area is categorized as arid and semi-arid lands (ASAL). The absence of quantitative data necessary for predicting land degradation and detecting critical management alternatives has curtailed the development of conservation practices applicable to ASALs. This has also prevented objective evaluation and adaptation of models and experiences developed elsewhere and hindered the rehabilitation of degraded land. The DMP has local objectives of mitigating land degradation in the desert margins in Kenya. While addressing its primary objective of alleviating land degradation, DMP is expected to make a significant reduction in the negative impacts associated with other factors that cause degradation processes.

In up-scaling identified best-bet technologies, two strategies were used: (i) strategies for the promotion of readily available technologies and (ii) approaches for participatory learning and innovation on knowledge-based issues including NRM. The methodologies and approaches used in up-scaling included establishment of small scale demonstration plots, on-farm trials, training and stakeholder workshops, information dissemination and exchange, and raising awareness to foster adoption of sustainable land use practices. DMP has participated in a number of initiatives to generate a policy and regulatory environment to encourage sustainable use of natural resources. Community-based management of natural resources, and monitoring and evaluation of the natural resource base with the pastoral communities was started in the DMP sites. This was implemented in close collaboration with the relevant stakeholders involved in extension related activities. They included extension services, international, national and local non governmental organizations (NGOs) and private sector who directly work with farmer groups and community based organizations (CBOs) as primary beneficiaries.

The existing and new farmer networks thus formed serve as the basis for the set-up of stakeholder platforms for all relevant partners involved in research and development activities in the sites. The district and location authorities, in collaboration with the NGOs and operational extension services are the main partners in this scaling-up and scaling-out process. Apart from being proactive in the development of strategies for improved uptake/up-scaling of research results, DMP also developed inventories of major agricultural extension and dissemination strategies that are operational within the benchmark sites. Thus the DMP-Kenya initiative includes up-scaling of four best-bet technologies: various rangeland/livestock management options, restoration of degraded lands, improved land, nutrient and water management and tree-crop/livestock interactions.

2. Description of the technology/strategy

Two strategies were used in up-scaling these technologies: (i) strategies for the promotion of readily available technologies and (ii) approaches for participatory learning and innovation on knowledge-based issues including NRM. The methodologies and approaches used in up-scaling included establishment of small-scale demonstration plots, on-farm trials, training and stakeholder workshops, information dissemination and exchange, and raising awareness to foster adoption of sustainable land use practices. Specific technologies being up-scaled include improvement of rangeland productivity, community based range resources monitoring and assessment, fodder conservation for home based livestock hers, rehabilitation of degraded lands, and bee keeping and honey production.

2.1. Improvement of rangeland productivity

Pastoralist and agro-pastoralists in the arid and semi-arid lands in Kenya occupy marginal lands where crop production under rainfed system is unreliable. This is due to the high evapotranspiration rate leading to crop failure and food insecurity. These areas have also been degraded and also mismanaged to such an extent that it will take decades to rehabilitate. This coupled with the ever increasing human population means that there is inadequate time available for recovery.

Range and livestock technologies can be used intensively to improve productivity of the marginal areas in the rangelands. Low levels of production in these areas are not only attributed to scarce and erratic rainfall, but also to low levels of technical skills by farmers. Proper exploitation of the range resources' potential through improved management can easily change the living standards of these farmers. The potential rangeland management practices that can be used to increase production in the semi-arid rangelands include range, plant and livestock related technologies.

2.1.1 The basis of the technology's success

Results from participatory evaluation of trials on pasture reseeding and related trials indicated farmers were encouraged by the increased forage for their livestock. The farmers have therefore expanded the areas under pastures and forages. A community based seed multiplication approach has been adopted to meet the high demand for seed. This group approach to on-farm trials and demonstrations has resulted in more rapid scaling up of technologies.

2.1.2 How is it implemented?

Improved livestock (cattle, camel and shoat dairy farming) technologies are targeted for up-scaling and demonstration in selected clusters. Currently DMP is working in five farmer clusters in the southern rangelands. In each cluster, five farmers were selected as contact demonstration farmers representing each village composed of about 50 to 60 active farmers. The demonstrations are carried out at the village level where all the farmers participate in adaptive research and development approaches.

2.1.3 Up-scaling the technology

This will be up-scaled in the DMP sites within the southern rangelands through promotion and support of farmer groups and CBOs that were registered during the Agrarian Reform Support Project (EU/ARSP), and Agroforestry for Integrated Development in Semi-arid Areas of Kenya (ARIDSAK) projects.

2.1.4 Contribution to the overall DMP project goal and objectives

The project will contribute to the project goal of biodiversity conservation and sustainable use of natural resources in the desert margins (Outputs 2 and 6).

2.1.5 Projected potential impact

With the adoption of improved range management technologies, it is expected that primary and secondary rangeland productivity and the living standards of the communities will be improved as well as reduction in rangeland degradation.

2.2 Community based range resources monitoring and assessment in Marsabit

Over the last two decades community-based natural resource management (CBNRM) has become an important strategy to conserve and sustainably use biodiversity in Africa. It is argued that the solution to the problem of resource degradation in developing countries depends also on local level institutions of resource management and the organizations to enforce them. Community resource management institutions and organizations are now receiving greater attention as a viable alternative to regulation by the state or privatization as a means of rectifying inefficiencies caused by attenuated property right systems and externalities. However, devolving rights to local communities to help build institutions for common property management may not be a sufficient condition for sustainable use of such resources. The challenge, however is the degree of effectiveness in internal governance for efficient application of community rules.

2.2.1 The basis of the technology's success

This approach was received with enthusiasm by the community members. This promises greater impact in enhancing environmental conservation efforts at the community level. To sensitize the wider community on the importance of biodiversity conservation, the results from the studies will be continuously made available to the community through workshops and outreach to institutions like schools. Since the community makes the initiatives, the results from these studies will plough feedback into the community policy structures for conservation of resources.

2.2.2 How is it implemented?

Conventionally, the Kenya Agricultural Research Institute's (KARI) Marsabit technical staff described the various resource attributes within established permanent transects and also clipped the herbaceous vegetation falling at specified intervals within transects. Data was collected along the 500 m long transects at every 100 m on grasses, herbs, forbs, shrubs and trees using the nested quadrat method. The paced transect method was used to record all species found within the transect area. Herbaceous, grass and shrub cover were clipped and weighed at the field level and oven dried at 150^0 C. Other attributes taken were vegetation cover, density and species frequency. Descriptions were also made of the vegetation species, and soil conditions and the results were compared with the community description. Two transects fall within the community livestock home range and the third transect outside the livestock home range.

For the community, data collected gives a general/subjective description of the area from their traditional indigenous knowledge perspective. Their method of recording and analysis depends more on memory and discussion than on written records. They described the environment and their observations which were documented in terms of vegetation suitability, cover, soil conditions and general observations on use or misuse of resources.

2.2.3 Up-scaling the technology

This technology will be up-scaled in the other DMP sites within Marsabit, and then to other parts of the country. The GEF funded Indigenous Vegetation Project (IVP) has shown interest in the data being collected and the approach of involving the community in resource management. IVP was also set to make transects for monitoring in collaboration with the community, hence this is an opportunity to share experiences. KARI Marsabit will also use the information and experiences for other districts within its mandate region.

2.2.4 Contribution to the overall DMP project goal and objectives

The project goal of conserving and restoring biodiversity in the desert margins is being met since the project is aimed at creating awareness on resource use dynamics and influence conservation policy at the grassroots level (Output 5 – policy advocacy and 7 – stakeholders' participation).

2.2.5 Projected potential impact

The greatest impact would be improvement in biodiversity within these areas that are already under pressure due to resource over utilization. Ecosystem services such as vegetation resources, reduction in soil erosion, improved water infiltration, among others will improve. The total area targeted is over 10,000 ha and this will benefit over 1,200 households.

2.3 Fodder conservation for home based livestock herds

Many changes have taken place within the drylands of Kenya which have led to changes in the vegetation structure. Several communities in the northern part of Kenya point to a good past in terms of vegetation resources endowment. However, they indicate that there has been a downward trend in vegetation attributes over the years. Some of the reasons given are increase in the demand for these resources due to population pressure, poverty and frequent droughts. These have severely affected regeneration. Livestock being the major livelihood in this region gives importance to the need for forage. However, this resource is becoming even scarcer with time, which is forcing pastoralists to move even further with their livestock. The implication is that livestock products (milk and meat) are unavailable to the community members that do not move with the livestock. This creates seasonal food shortages at the household level. If this problem is not addressed, the remaining community members may resort to destructive forms of livelihood like charcoal burning or logging like the case of Ngurunit in Marsabit district.

2.3.1. The basis of the technology's success

Since the technology was tested within the EU/ARSP II project, success is bound to be high. The challenges of the recent drought, which made the government provide hay as part of relief efforts, has made the community take the initiatives of fodder conservation seriously. The only challenge will be provision of grass seeds, which imply timely harvesting of grass seeds or sourcing of fodder germplasm.

2.3.2. How is it implemented?

Community members in Ngurunit and Kalacha involved in this initiative are spillovers from the EU/ARSP II project. This is a community driven initiative apart from the technical support from KARI.

2.3.3. Up-scaling the technology

These initiatives are being carried out in Ngurunit and Kalacha where the oasis area offers opportunity for fodder establishment. The community in this area has reaped incomes from the sale of hay since the surrounding areas are harsh and the need for fodder during the dry seasons is inevitable. Opportunity for up-scaling is within areas that have an oasis environment like North Horr and the Marsabit Mountain and other areas within KARI Marsabit mandate area.

2.3.4 Contribution to the overall DMP project goal and objectives

This technology contributes to the project Output on sustainable alternative livelihood options (Output 4).

2.3.5 Projected potential impact

The direct benefit of the initiative would be provision of fodder for the home based herds and secure food security at the household level. By implication, the provision of fodder reduces the pressure on vegetation resources hence allowing regeneration and conservation of biodiversity.

2.4 Rehabilitation of degraded rangelands

The rangelands are characterized by low and erratic rainfall, prolonged dry periods and frequent droughts. The soils are fragile and easily degraded and also varied depending on the parent material, mode of formation and topography. Thus, rangelands have a relatively low production potential. The most common types of degradation in the rangelands are degradation of the soil, vegetation and animal species. There is need to develop and disseminate appropriate technologies for proper utilization of the rangelands and rehabilitation of degraded areas. Technologies have been developed and disseminated over the years to assist the users of the rangelands in optimizing their production and rehabilitating the degraded areas. There is need to continue supporting these efforts for improved and sustainable production in the rangelands.

The technologies being up-scaled are mainly in soil and water management and improvement of primary productivity. The soil and water management technologies are:

(i) Run-off harvesting for improving soil moisture
(ii) Construction of water and soil micro-catchments
(iii) Construction of modified terraces
(iv) Restoration of gully eroded rangelands, and
(v) Development and adoption of integrated soil/water nutrient management methods.

Technologies for the improvement of primary productivity are:

(i) Plant species enrichment that involves introduction or increasing of the germplasm for improving ground cover and production.
(ii) Bush management technologies that involve reduction of the woody vegetation to allow for increased herbaceous production.

2.4.1 The basis for the technology's success

The potential gain from increased herbage coupled with reduced soil loss and degradation makes this technology an option for successful reseeding/revegetation of denuded ranges. However, it is only possible where farmers have control and access of the land and where protection can be effected until the plants are fully established. There is also need to out-scale the activities to cover more sites and communities both within the southern rangelands and beyond.

2.4.2 How is it implemented?

The technologies were implemented using on-farm trials and demonstrations carried out at the village level where all the farmers were involved through participatory adaptive research and development approaches.

2.4.3 Up-scaling the technology

The target areas for up-scaling these technologies are Makindu and Kibwezi divisions in Makueni district and Mashuru and Loitoktok divisions of Kajiado district in the southern rangelands. The project will target about one hundred households in each division over a three-year period. This will result in about four hundred households being covered in the two districts with each having one or more improved technology.

2.4.4 Contribution to the overall DMP project goal and objectives

The project will contribute to the DMP goal of sustainable NRM and biodiversity conservation (Output 6).

2.4.5 Projected potential impact

The potential impacts are:

1. An increase of 10% in production through increased production in rehabilitated areas over a three year period.
2. A 10% increase in household nutrition through utilization of increased primary and secondary production over a three year period.
3. Improved household income through sale of increased primary and secondary production.

2.5 Rehabilitation of deserts through planting of *Acacia senegal* trees in micro-catchments

The Acacia Operation Project is a project supporting food security and rural development of gums and resins in sub-Saharan African countries (Burkina Faso, Chad, Kenya, Niger, Senegal and Sudan). This project aims to rehabilitate degraded land by planting *Acacia senegal* using novel water harvesting technologies, improving livelihoods through promotion of gums and resins production. The project is supported by FAO through Kenya Forestry Research Institute (KEFRI) in the context of natural gums and resins in Africa-Natural Gums and Resins in Africa (NGARA). The delphino plow was used for water harvesting in this project.

In Kenya, the project operates in Samburu and Marsabit districts and implements its activities in collaboration with DMP. In Samburu district the project site is Sereolipi while in Marsabit the sites are: Merille, Laisamis, Logologo, North Horr, Elgade and Gas. A major threat in these areas is desertification, frequent droughts and poverty.

2.5.1 The basis of the technology's success

The potential of production of gums and resins as alternative livelihoods and diversification of the production systems forms the basis of the technologies success.

2.5.2 How is it implemented?

The approach used aimed at creating a synergy between nature and modern technology in improving management of natural resources. The community was involved in identification of potential sites for development of plantations for gums and resin production, before micro-catchments are ploughed (with delphino). There has also been capacity building on markets and income diversification as well as training in dryland food production and utilization to realize immediate benefits from the plantations.

2.5.3 Up-scaling the technology

Since this is an initial phase of three years, the potential for up-scaling is high with the envisaged ten-year project period since more communities are demanding this technology.

2.5.4 Contribution to the overall DMP project goal and objectives

The technology will contribute to sustainable development, food security and fight against desertification through the promotion and integration of gums and resins in rural economies as an alternative livelihood (Output 4).

2.5.5 Projected potential impact

About 342.7 ha were planted with *Acacia senegal* seeds/seedlings and drought tolerant crops. The results indicate that *A. senegal* can be successfully established in degraded sites. However, more trials need to be conducted before concrete recommendations on integration of crops with *A. Senegal*. Challenges include cultural bias pastoral livestock keeping as opposed to agro-silvo-pastoralism and communal land ownership. These challenges may be overcome only in the course and framework of a long term project. However if short duration livelihood options are supported within the project framework, it is possible that there will be more willingness on part of the communities to participate in the project and adopt technologies that are being tested.

2.6 Bee keeping and honey production

In key zones of the high altitude and *Acacia* riverine areas of northern Kenya, several factors lead to encroachment of natural resources. These include the increasing pastoral population coupled with increasing sedentarization, and resulting in land degradation and depletion of biodiversity, which threaten the livestock-based livelihood system of pastoral people. Several of the non-pastoral livelihood activities are not compatible with conservation and threaten resources in these key areas. To broaden their livestock base and diversify livelihood sources and income generation, settled pastoralists in Ndotto Mountain ranges practice traditional beekeeping as an alternative livelihood source, which is highly compatible with biodiversity conservation. The traditional system, although well adapted to the ecology, socioeconomic and cultural conditions of beekeepers, bee products derived from the system do not conform to the required market standards. This has substantially reduced their incomes. In the traditional system, poor handling of bees especially during harvesting can result in high incidences of absconding and loss of honey crop.

2.6.1 The basis of the technology's success

Constraints and solutions to factors limiting traditional beekeeping were identified in collaboration with the target community. In feedback workshops, the participants identified technologies and priority areas for training. To introduce technologies and train traditional beekeepers, a farmer-to-farmer approach involving participatory training and demonstrations were used. Integrating women in beekeeping was necessary, since the traditional system was mainly male dominated.

2.6.2 How is it implemented?

Survey and informal group discussions were carried out to document the potential of beekeeping and also inventory of traditional skills and knowledge. In collaboration with target communities priority areas for training and appropriate beekeeping technologies were identified. To refine the results and discuss on survey findings feedback workshops were conducted. Traditional beekeepers and representatives of women groups and local traders were taken on an external study tour to visit and learn from other beekeepers. The introduction of modern beekeeping technologies was carried out through participatory trainings and demonstrations. The initiatives were jointly implemented by traditional beekeepers in the target area, women groups involved in postharvest of hive products, local honey traders, community leaders and elders handling cases of hive vandalism, experienced model local beekeepers, the livestock extension department and KARI research staff.

2.6.3 Up-scaling the technology

The beekeeping interventions will be replicated to other sites with beekeeping potential.

2.6.4 Contribution to overall DMP goals and objectives

Beekeeping is a viable alternative livelihood source (Output 4) that can generate additional income for the households and thus alleviate poverty, whilst contributing to the maintenance and conservation of biodiversity. If more communal land is reserved for family and clan apiaries, which is accompanied by control of resources, this allows propagation of wild plants and animals and thus maintenance of biodiversity.

2.6.5 Project potential impact

At the moment about 80 households are engaged in beekeeping and bee products processing activities, with an estimated gross income of about Ksh 600,000.00, which is very high income in this pastoral setting. At the terminal stage of the project, it is expected that beekeepers will increase income from sale of more crude honey to about Ksh 3 million and about 200 households will be practicing beekeeping. There will be increased biodiversity as the area in the communal land reserved for traditional beekeeping will increase.

2.7. Improved land, nutrient and water management

Agricultural production in ASALs is limited by low and erratic rainfall, high transpiration rates and generally fragile ecosystems which are not suitable for rainfed agriculture. To improve crop production in these areas, sustainable drought and dry spell mitigation farming methods are required.

Rainwater harvesting using tied ridges and open ridges are some of the cheap methods of mitigating dry spells. In Makueni, DMP has demonstrated that tied ridges increase maize yields by over 50% above the conventional flat tillage practices. The increase in yield, however, was significant when tied ridges are combined with integrated nutrient management (INM). The objective of the project is therefore to promote and upscale these technologies for crop production and environment conservation in the semi-arid areas of Makueni, Kajiado, Turkana and Marsabit districts. The hypothesis is that combining water harvesting techniques with improved soil fertility will result in higher efficiency of resources and increase in crop yields in the ASALs.

2.7.1 The basis for the technology's success

Among various water conservation technologies available, tied ridging offers maximum potential for water conservation. This technique involves creating a series of closely spaced rectangular depressions that prevent redistribution of water within the field while concentrating water in the furrow. This allows rainwater to infiltrate into the soil, preventing runoff and increasing moisture retention in the soil profile. However, both positive and negative effects of tied ridging have been noted across seasons as well as locations in other parts of the world where studies have been carried out. The contradictions may partly be due to variation in soil and climatic characteristics among sites tested. Thus both soil characteristics and rainfall regime should be considered when evaluating the effectiveness of tied-ridging in the ASALs. Studies have shown that tied ridges, when combined with fertility management, increase crop yields by 50-100% when compared to yields from flat planting. Thus optimization of land productivity should aim at having production systems that address both soil nutrients and water management.

2.7.2 Up-scaling tied ridging and INM technology

Up-scaling trials were conducted on farmers' fields in DMP sites in Makueni, Kajiado, Turkana and Marsabit districts during the short rains of 2005 and long rains of 2006. Water harvesting methods consisted of tied-ridging and open furrows while the INM treatments were: (1) manure (10 t/ha), (2) manure (5 t/ha), (3) manure (10 t/ha) + 20 kg N/ha + 20 kg $P_2 0_5$, (4) manure (5 t/ha) + 20 kg N/ha + 20 kg $P_2 0_5$, (5) control (farmers' practice with no fertilizers). The aim of up-scaling was to train farmers on how to harvest rainwater (using tied ridges and contour furrows) and the use of fertilizers and animal manure for soil moisture conservation and soil fertility improvement. Farmers were trained through demonstrations in selected farmers' fields. A total of five complete mother trials and 23 baby trials were established in farmers' fields in the southern rangelands in 2005. However, the trials were adversely affected by severe drought conditions in Kenya. Other additional trials were established in Turkana and Marsabit in the long rains of 2006.

Prior Learning Assessment and Recognition or PLAR is a target group-oriented approach involving all the stakeholders (researchers, development agents and farmers/producers), that will be used after at least two seasons of on-farm trials. In the establishment of trials, partners included DMP research scientists from collaborating institutions that included the TSBF Institute (Tropical Soil Biology and Fertility Institute) of CIAT (Centro Internacional de Agricultura Tropical), KEFRI, KARI, extension staff from the departments of government ministries, NGOs and CBOs from the DMP sites.

2.7.3 Contribution to the overall DMP project goal and objectives

Up-scaling water harvesting and INM technologies to sustain food production and improve rural livelihoods will contribute towards the DMP project goal of arresting land degradation. The broad objective is to foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crops, trees, and animals. This activity falls under the promotion of soil fertility component of the Output 6 on scaling up NRM options.

2.7.4 Projected potential impact

Water harvesting and INM strategies will increase crop production in ASALs while conserving the environment. This will lead to improved food security and increased household incomes. The project aims at 50% of the target populations in DMP sites having one or two integrated soil fertility management technologies by the end the project in 2008.

2.8 Tree-crop/livestock interactions

Tree-crop/livestock integration offers a promising opportunity for intensifying agricultural production and increasing ecological integrity so as to have a positive impact on livelihoods and NRM in mixed farming systems. For poor-resource smallholders, rotations of various crops, forage legumes, trees and use of manure helps maintain soil biodiversity cheaply, minimize soil erosion and conserve water.
Up-scaling of *Melia volkensii (*a type of timber) and mangoes was selected as a viable alternative livelihood for enhancing biodiversity conservation, along with beekeeping.

2.8.1 The basis for the technology's success

Kenya's forest cover (about 1.7%) is far below the globally recommended 10% for any country's total surface area. This problem is aggravated by expansion of agricultural land. Kenya is therefore increasingly becoming an importer of forestry related products such as timber and poles. Decreasing forest cover is also contributing to loss of biodiversity and reduction of carbon. Because of the preference of agricultural production in the high potential areas, forest expansion can only be feasible in other areas that are less favorable to crop agriculture. However, this concept is constrained by scarcity of information on appropriate species and technologies.

This challenge has been addressed by KEFRI through the screening of species and use of appropriate forestry interventions. The process resulted in the selection of *Melia volkensii*. Over the last two decades, *Melia volkensii* (Gürke.) has received great research attention because of its socioeconomic importance in the drylands. This multipurpose tree species is endemic to the ASALs of eastern Africa with greater distribution range in Kenya. *Melia* is used for construction timber, fuelwood, fodder (fruit and leaves), medicine (bark), bee forage, mulch and green leaf manure. Similarly, mango production also has high potential in ASALs and has the same challenges as *Melia*. Both of these crops were considered simultaneously for up-scaling as they perform equally well under similar ASAL conditions.

2.8.2 How it is implemented?

Propagation of *Melia* through seeds has long been a serious impediment to its planting in Kenya. KEFRI researched this aspect and has come up with production guidelines that are not yet widely adopted by farmers. Besides propagation, silvi-cultural management of the species is still at infancy and needs to be refined before recommendations are disseminated to stakeholders. DMP has responded to these needs and is currently up-scaling *Melia* through:

(a) **Capacity building on seedling production for farmers**. The training focuses on timing of seed maturity, de-pulping of *Melia* fruits, seed extraction, seed pre-treatment, sowing, pricking out and tending of pricked out seedlings. Training is necessary because the species is highly sensitive to weather and environmental conditions.
(b) **Silvi-cultural management**. Farmers are trained on tree management to improve production of various *Melia* products. Timber production, pruning and spacing are the major training aspects.
(c) **On-station seedling production**. This was initiated during Phase II to meet the rising demand for *Melia* seedlings. This will be scaled down as farmers are trained to produce seedlings on farm.

The key challenges to mango production is timely production of quality fruits in quantities that justifies selling in lucrative markets. Suitable varieties, grafting techniques, integrated soil water and fertility management practices, and pest and disease management options have been identified for mangoes. In addition, there have been proposals by stakeholders on marketing and value adding strategies through collective action, networking, packaging and transportation of the fruit. DMP has been training farmers on seedling production, availability of better varieties and crop management.

2.8.3 Contribution to overall DMP project goals and objectives

Up-scaling of *Melia* and mango addresses several DMP objectives and provides synergy to multilateral environmental agreements on biodiversity conservation and climate change. By providing an alternative source for forestry products like timber, the pressure on highlands forests is expected to reduce in the long term, and this contributes to biodiversity conservation since highland forests are more endowed with biological diversity. The gains from increased planting of *Melia* will eventually lead to conservation of highland forests by way of increase in carbon sequestration. In addition to these benefits, the sale of raw and processed products will contribute to household incomes, providing alternative livelihoods for local communities. Mangoes will, in addition to its contribution to food, provide farmers with some income.

2.8.4 Projected impact at the end of the project

Local communities will become self reliant in the production of good quality seedlings. Capacity building and enhanced ree management skills will empower farmers in production of diverse goods and services. Thus marginal areas in Kenya will have alternative sources of timber as well as additional income.

2.8.5 Contribution to overall DMP project goals and objectives

Up-scaling of mangoes and *Melia* addresses several DMP objectives that include poverty alleviation and mitigating land degradation. Increased mango production and marketing will not only enhance income but improve nutritional levels of the targeted populations. The increased acreage under these trees will increase land-under-vegetation cover in the drylands and thus help enhance carbon sequestration.

Best-bet technologies in West and Central Africa

A. Niger

1. The context

The challenges faced by Niger in the area of land degradation and biodiversity conservation are enormous. Over the years water and wind erosion have caused land degradation, soil crusting and low soil fertility, which adversely affect crop yields and food production, thereby impacting negatively on the livelihoods of the rural communities. In addition there is considerable loss of tree population on the plateau and of biodiversity as a consequence of land degradation. For example, the loss of vegetation cover (ligneous and herbaceous) in one of the DMP benchmark sites in Koure is adversely affecting the survival of the last giraffes of West Africa.

Failure to address this problem of land degradation and loss of biodiversity may lead to the following:

- Decimation of the population of giraffes (about 170 heads presently);
- Famine and loss of livestock by the human inhabitants at the project site through degraded crop field and rangeland;
- Loss of carbon sequestration from poor growth of trees and overexploitation of forests for wood and other forest products;
- Increased vulnerability to poverty and climatic shocks by the communities because more than 80% of the population depends on this environment for their livelihood. The famine in Maradi region (the second DMP site) in 2005 is a good example.

2. Description of the technology/strategy

To address the problems described above, DMP-GEF Niger has opted to use three major technologies/strategies:

- Management and value addition for the giraffe region of Kouré, western Niger
- Land degradation control using water harvesting techniques for the production of trees and pastures
- Use of fertilizer microdosing techniques and "warrantage" credit system to improve soil fertility and increase the income of rural communities

2.1. Management and valorization of the giraffe region of Kouré, western Niger

This technology is based on various component technologies tested separately, but put together under the DMP-GEF Niger for the Kouré site to address a complex problem of protecting the giraffes through better management of land and human environment.

2.1.1. The basis of the technology's success

The plateaus of western Niger have been a test ground for more than 30 years for the plantation of native trees to improve the tiger bush status. These studies were based on the understanding of water redistribution in a tiger bush system, the mechanisms of tree bands establishment to form tiger bush, and the use of man made structures (half-moons, trenches, etc.) to improve water storage and reduce run off. There is also a need to reduce competition between wild animals (giraffes) and human (crop land, forest use for fuel and cash) to enhance success. In addition, the giraffes represent an important source of income for local population through tourism.

2.1.2. How is it implemented?

The implementation strategy focused on planting trees on the plateaus and in specific areas (arboreta) to provide fodder for the giraffes and fuel wood/other forest products for the inhabitants of the region. It also includes the conservation of water sources (both on the plateaus and in the Dallols) for the giraffes to remain in the site even during dry months but also serves as fishing grounds for the local people and nesting places for migrating birds. To complete the strategy, to prevent encroaching farmland on the forest land (common in extensive agriculture), improvement of soil fertility in cropped land is achieved by the use of both mineral and organic fertilizer (microdosing+warrantage) for increased crops production and increased income.

This work is carried out in close collaboration with all the stakeholders in the region. The expertise of these partners is invaluable in the implementation of the technologies. The major partners include:

- DFPP (Direction Faune Pêche et Pisciculture of the Ministry of Environment), responsible for this activity;
- DE (Direction de l'environnement et services déconcentrés), responsible for environment protection (wild trees, forestry and other natural areas) in the country;
- DMP-GEF Niger;
- ECOPAS, (Ecosystéme Protégés en Afriqne Sahélienne) a regional project dealing with natural resources protection;
- AJPN, Association des Jeunes Pour la Protection de la Nature a youth association for the protection of the giraffes;
- Local tourist guides;
- Ministry of Agriculture (DCV, African Network for Horticulture Development (RADHORT)/FAO project);
- ATPN (Association of Traditional Practitioners of Niger);
- ABC-écologie, an NGO interested in many NRM issues (rangeland management, cropping systems, land degradation, etc.) intervening in Mayahi (second DMP site);
- Local authorities (administrative and traditional);
- The rural communities living in the site.

The partnership has worked well and has attracted the interest of other partners such as the " Oasis Sahelien" of Japan International Research Center for Agricultural Sciences (JIRCAS) proposing to work on the use of water reserves for crop production.

2.1.3. Up-scaling the technology

Up-scaling is done on only some components of the technology since giraffes are only found in this region of Niger. For example, planting trees, building of water conservation structures, water and nutrients management activities, best practices of wildlife management (eg, honey extraction and processing) etc. are already being up-scaled within and beyond the project site: eg, by the Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricole (CORAF) or West and Central African Council for Agricultural Research and Development (WECARD) project. The areas for up-scaling are identified by communities, specific interest groups (women groups for vegetable production), or development projects. The technology can be applied to other countries if adapted to local specific constraints and stakeholders' needs. Partners such as JIRCAS and the President's Special Program will assist in the up-scaling phase. The major constraint to a successful up-scaling of the project is fluctuation in annual rainfall which can affect establishment of the trees and germination of the pasture species and eventually biomass yield. Besides, the implementation of the technology is limited by the high level of stakeholders' vulnerability which reduces their participation. Hence, activities whose results have no direct or immediate impact did not interest them.

2.1.4 Contribution to the overall DMP project goal and objectives

This technology contributes to the overall goal of biodiversity conservation and restoration. It also contributes to the following specific objectives and project outputs:

- Document and evaluate, with the participation of farmers, NGOs and NARS, current indigenous soil, water, nutrient, vegetation and livestock management practices for arresting land degradation and to identify socioeconomic constraints to the adoption of improved management practices (Output 1.3 – documentation of indigenous knowledge; Output 1.6 – regeneration of vegetal species; Output 7.1 – participation of vulnerable groups; Output 7.2 – permanent dialogue framework).
- Develop and foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crops, trees and animals to enhance food security, income generation and ecosystem resilience in the desert margins (Output 4.2 – empowering the local communities; Output 4.3 – implementation of best-bet options; Output 6.1 – promotion of soil fertility; Output 6.3 – promotion of multiple land use systems).
- Promote more efficient drought-management policies and strategies (Output 5.3 – implement policies; Output 6.2 – promotion of integrated land and pastoral spaces).

- Facilitate the exchange of technologies and information among farmers, communities, scientists, development practitioners and policy makers (Output 7.1 – participation of vulnerable groups; Output 7.2 – permanent dialogue framework).

2.1.5 Projected potential impact

The projected impacts include:

- The sustainable conservation of giraffes in the site and increase in their population by improving natural fodder, water availability and reducing conflict with local farmers;
- The restoration of vegetation cover and carbon sequestration improvement of households and communities livelihoods through money generating activities and better crops and livestock production;
- These impact will reach more than 20000 inhabitants and cover more than 83000 ha representing the giraffe's main living area.

2.2. Land degradation control using water harvesting techniques for trees and pastures production

2.2.1 The basis of the technology's success

Niger is one of the leading countries in West Africa when it comes to land degradation control using water harvesting techniques combined with tree plantation, controlling invasive rangeland plant species, or denuded areas restoration. Though there have been many projects to combat desertification since 1960, little has been done on pasture restoration in agricultural areas such as the two DMP-GEF sites. This technology combines both water harvesting techniques with tree plantation and native pasture restoration. Greater responsibility is given to local communities at all stages of the implementation of this technology (design, implementation, and management).

2.2.2 How is it implemented?

Discussions were held between scientists and other stakeholders to identify constraints and potential solutions (Phase I of DMP). In addition, the stakeholders were trained in the use of the technology (Phase II of DMP) and participatory implementation of the activities is being carried out (Phase II and III). Locally adapted and multi-usage (fodder, wood, medicinal) herbaceous and tree species were planted in the project sites. The stakeholders ensure protection of the degraded areas being reclaimed against grazing by the livestock and lopping so that vegetation can grow normally and herbaceous species produce seed for dissemination and propagation. Partners include scientists, technicians from the Ministry of Environment, NGOs (ABC-écologie), local population and development projects in the area. The President's Special Program will be a potential partner. So far, this technology is a high resource demanding activity in terms of labor and funds. On-going similar activities in the two DMP sites from other donors have set ground rules that the DMP has to follow to get support from communities. In a few cases this contradicts the full participatory approach proposed by DMP-GEF.

2.2.3 Up-scaling the technology

Up-scaling is done by identifying progressively (on a yearly basis) the new specific areas to be managed. Areas for up-scaling are identified jointly with the communities and local Ministry of Environment technicians to comply with local and national development plans. The technology is already applied in other countries such as Burkina Faso and Mali. The Ministry of Environment will assist in the
up-scaling phase. The major constraints of up-scaling this technology include high requirement for funds and labor. Other constraint is the influence of other projects in the location, which are not using the participatory approach and may undermine participation of the local communities.

2.2.4 Contribution to the overall DMP project goal and objectives

This technology contributes to the following specific objectives and outputs of the DMP-GEF project:

- Document and evaluate, with the participation of farmers, NGOs and NARS, current indigenous soil, water, nutrient, vegetation and livestock management practices for arresting land degradation and to identify socioeconomic constraints to the adoption of improved management practices (Output 1.3 – documentation of

indigenous knowledge; Output 1.6 – regeneration of vegetal species; Output 7.1 – participation of vulnerable groups; Output 7.2 – permanent dialogue framework).
- Develop and foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crops, trees and animals to enhance food security, income generation and ecosystem resilience in the desert margins (Output 4.2 – empowering the local communities; Output 4.3 – implementation of best-bet options; Output 6.1 – promotion of soil fertility; Output 6.3 – promotion of multiple land use systems).
- Promote more efficient drought-management policies and strategies (Output 5.3 – implement policies; Output 6.2 – promotion of integrated land and pastoral spaces).
- Facilitate the exchange of technologies and information among farmers, communities, scientists, development practitioners, and policy makers (Output 7.1 – participation of vulnerable groups; Output 7.2 – permanent dialogue framework).
- Empower rural stakeholders to manage their natural resources by sensitizing and training them in using local species for restoration and better control of grazing (Output 7). They know more about the principal ecological factors which lead to land degradation and how to alleviate their effects.

2.2.5 Projected potential impact

It is expected that more than 230,000 trees and 1500 bags of seeds for pasture restoration will be planted each year and will roughly give carbon accumulation of 7.5 t/ha/yr. This will lead to increased income/reduced poverty, increased bio-diversity and increased capacity of the local communities. An area larger than 50,000 ha will be restored and the vegetation will be increased in the Baban rafi area and neighbors and the agricultural zone of Mayahi.

2.3 Use of fertilizer microdosing and 'warrantage' credit system to improve soil fertility and increase income

2.3.1 The basis of the technology's success

Crop yields in Niger are low due to abiotic factors such as low and erratic rainfall and poor soil fertility. Furthermore small-scale farmers have little or virtually no access to credit to purchase inputs like fertilizers and improved seeds. The technology of fertilizer micro-dosing which consists of applying small quantities of fertilizer in the hill of plants has proved to increase fertilizer use efficiency, improve yield and reduce costs of inputs. The 'warrantage system' or inventory credit system enables the farmers to get good prices for his products, enhance his access to cash and inputs and increase his income. More than 5000 on-farm demonstration trials have been conducted by Projet Intrants FAO, INRAN, ICRISAT on fertilizer micro-dosing on cereal crops (millet and sorghum) and more recently on other crops (cowpea, sesame, etc). The results of these trials indicated that millet yield increased by 44 to 120% while income of farmers increased by 52 to 134% using the fertilizer micro-dosing technology and warrantage systems. DMP-GEF Niger has used this approach and linked it to various activities for income generation, natural resources conservation, biodiversity conservation and use in its two sites of Kouré and Mayahi/Baban Rafi.

2.3.2 How is it implemented?

This technology is being implemented for soil fertility improvement, land degradation control, natural resources conservation and use (eg, honey production) and biodiversity improvement (seed production) using the large network of warrantage groups installed by the Projet Intrants FAO and according to the specific needs and activities of stakeholders in the DMP-GEF. The main partner for the implementation of this technology is Projet Intrants FAO. Other partners include farmers associations (seed producers, bee keepers, FUMA Gaskya etc). The technology is successful, but has strict requirements. DMP-GEF needs to establish the system in villages where it does not exist following a request from local stakeholders and their fulfillment of some prerequisites.

2.3.3 Up-scaling the technology

The technology is being up-scaled through dissemination to other villages/groups based upon request from them. Training of the farmers is conducted by Projet Intrants FAO. The technology can be applied to other countries, and tests are actually underway in Burkina Faso, Mali and Senegal. Partners who may assist in the up-scaling phase are all the rural development projects or NGOs interested in crop/animal production, natural resources management, etc.

The major constraints to the continued success of this technology are fluctuation in rainfall, which may negatively affect crop yield and continued availability of credit for the warrantage system.

2.3.4 Contribution to the overall DMP project goal and objectives

This technology will contribute to the overall DMP-GEF goal and to the following specific objectives:

- Develop and foster improved and integrated soil, water, nutrient, vegetation and livestock management technologies and policies to achieve greater productivity of crops, trees and animals to enhance food security, income generation and ecosystem resilience in the desert margins (Output 1.3 – documentation of indigenous knowledge; Output 1.6 – regeneration of vegetal species; Output 7.1 – participation of vulnerable groups; Output 7.2 – permanent dialogue framework).
- Evaluate the impact and assist in designing policies, programs and institutional options that influence the incentives for farmers and communities to adopt improved resource management practices (Output 4.2 – empowering the local communities; Output 4.3 – implementation of best-bet options; Output 6.1 – promotion of soil fertility; Output 6.3 – promotion of multiple land use systems).
- Promote more efficient drought-management policies and strategies (Output 5.3 – implement policies; Output 6.2 – promotion of integrated land and pastoral spaces).
- Facilitate the exchange of technologies and information among farmers, communities, scientists, development practitioners and policy makers (Output 7.1 – participation of vulnerable groups; Output 7.2 – Permanent dialogue framework).

2.3.5 Projected potential impact

The technology will impact on land productivity, income generation, and bio-diversity increase for households and communities.

The state of implementation of these technologies in 2005 is summarized in the Table 7. There are some levels of achievements on each of these technologies in 2005.

Table 7. Summary of achievements by technology in 2005 in Niger.

Major intervention	DMP achievements in 2005	Targets involved	Partners' inputs
1. Management and valorization of the giraffe region at Kouré	1) Elaboration of 2004 tourist guide (small and big size) and identification guide of birds for users 1a) Training of 20 tourist guides 2) Construction of half-moons and other works on 5,902 ha of degraded land and plateaus with trees plantation (23 000 plants) 3) transfer of 1900 plants of grafted *Ziziphus* 4) Recovery of 10 ha of permanent pond on cutting of *Typha australis*	More than 700 families of 10 villages neighboring the giraffes zones 13000 farm families, 80000 ha 50 fisherman families	Control of giraffe population (mise en défens) and help the guides in putting in place the infrastructure at Kouré and Kanaré (by ECOPAS) Construction of open wells and bore holes by ASGN at Koure zone and demi-lune on 20 ha
2. Land degradation control at the DMP sites	1) 18,212 ha with half-moons and other land recovery work seeded with forage grasses on 42000 trenches, 26000 trees planted and 34 bags of various herbaceous species used at Baban Rafi and/or Mayahi 2) 5416 scions of ziziphus treated in about 200 ha 3) 30 producers trained in RNA at Baban Rafi	More than 10000 persons involved: an equivalent of 22 rural markets 15 families 300 families	1200 ha mis en défens treated; managed and controlled and exploited by 22 fuel wood rural markets (36,902 ha) 4,476 ha restored by various partners CORAF (with aid of CRS), PADL, Mayahi & PAM,

			PAFN at Mayahi
3. Use of fertilizer micro dosing techniques and warrantage	1) 335 families involved in various actions of microdosing and warrantage based on improved varieties of millet, sorghum, cowpea, sesame; control of ragouva, using of mineral and organic fertilizer 2) 40 producers trained in land degradation and desertification and management of natural resources. Edition of agrometeorology monthly newsletter of Gabi for the 2nd semester of 2005.	335 families	Various training by technical departments, project and NGOs

ECOPAS = Ecosysteme Protégé Sahelien; ASGN = Association pour la Sauvegarde de la Giraffe au Niger; CORAF = Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricole; CRS = Catholic Relief Service; PADL = Projet d' Amenagement pour le Developpement Local; PAM = Program Alimentaire Mondial; PAFN = Projet Amenagement des Forets Naturelles

B. Burkina Faso

1. The context

Burkina Faso is seriously affected by land degradation and desertification. Every year, thousands of hectares of woodlands disappear due to clearance, bush fires, excessive cutting of wood, overgrazing and lopping. Land degradation, caused by water and wind erosion, renders lands unfertile. The arable lands have reduced significantly due to land degradation. This has further increased poverty in the rural areas. DMP-GEF project therefore aims to combat land degradation in the desert margins areas (rainy season 100 to 600 mm) through participatory research and the strengthening of institutional capacity. Specific objectives are to develop strategies to arrest land degradation, reduce soil erosion and the loss of biodiversity.

2. Description of the technology/strategy

2.1 Management of degraded lands using the delphino plow, half-moons and seeding

This technology of land rehabilitation is based on the use of the delphino plow, which constructs half-moons that are spaced 5 m apart. During the dry season seeds of herbaceous plants and shrubs are transported by the wind and collected in these half-moons. During the rainy season, the half-moons collect runoff and thus enhance water infiltration and storage. This water is made available to the trees, grasses and shrubs seeds and seedlings thereby promoting their growth. The half-moons are constructed following the convex lines of the curves. Rehabilitation of degraded lands was done in the sites of DMP Burkina Faso and other research/development projects, namely Banh, Tougouri, Katchari and Oursi. The work was carried out either at the village or household level.

2.1.1 The basis of the technology's success

To achieve the rehabilitation of degraded lands the following conditions have to be met:

- Favorable Harmattan winds carrying seeds of herbaceous plants and shrubs into the half-moons. These half-moons are built in such a way that they can collect and retain seeds, store water and reduce run off. It is also advisable to do some seeding and tree planting under certain conditions.
- Based on the experience of DMP work in Burkina Faso, it was observed that there should a minimum amount of rainfall for the success of the activity. For example, the results from the Banh site were not as good as those from the other sites due to low rainfall in 2005.
- The managed lands must be protected against grazing animals. There should be no grazing on these lands that are being rehabilitated for one to two years depending on the sites to ensure that the grasses and shrubs seedlings are well established. In this regard the DMP team has conducted a series of awareness campaigns of rural

communities to find ways and means to preserve managed areas. The awareness campaigns were conducted in the villages concerned by DMP-GEF project to identify with the farmers means to protect the managed areas within the context of their socioeconomic set up. Ways to protect the areas include permanent rural security people in Oursi and Tougouri to whom bicycles are provided as incentives while the sites of Banh and Katchari preferred a rotation system to monitor the managed areas by households.

2.1.2 How is it implemented?

During the first year of the application of this technology tests were carried out whereby the degraded lands in each site were split into three:

- The first plot was reserved for cropping activities involving plant species selected by farmers, which have high market value in the area (sesame, cowpea, groundnut, Hibiscus, etc.)
- The second part was earmarked for agro-pastoralist activities with species tested and selected by farmers from on-farm research (Institut de l'enrironnement et de rechereches agricoles/Kamboinse) and found useful in producing forage and improving the soil (viz. cowpea and *Andropogon gayanus*).
- The third plot was used for horticulture.

These activities were carried out in collaboration with the decentralized state agencies such as the Ministry of Agriculture and water resources, Ministry of Animal Resources, Ministry of Environment and welfare, NGOs and rural communities.

Pictures taken from the site highlight the work done and show the restoration of herbaceous species and also the re-appearance of insects and termites that have beneficial effects on the soil fertility and structure. In the fields, the technology is a success as all the rehabilitated lands are covered by vegetation along the half-moon lines. A total of 320 ha was regenerated as follows:

Banh	100 ha
Tougouri	100 ha
Dori (Katchari)	60 ha
Oursi	60 ha

2.1.3. Up-scaling the technology

The technology of the rehabilitation of degraded lands using the delphino plow was tested on a large scale in Burkina Faso and gave very good results. DMP project partners in the area such as 'Projet Front de Terre' of the Ministry of Environment, Operation Plan Acacia of the same ministry and more recently the Project Food Security in the rehabilitation of degraded lands have made good use of the technology. However, the main constraint in the promotion of the technology is its high cost (US$90 per hectare), which many local populations cannot afford even if they are well organized.

2.1.4 Contribution to the overall DMP project goal and objectives

The main contribution of this technology to the DMP project goal and outputs is in the restoration of biodiversity (Output 2 – development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems) and in the increase of rehabilitated lands that can be used for cropping. The trees planted by the DMP-GEF project are composed of species that can generate income: *Acacia senegal* (gum arabic) and *Zizyphus mauritiana* (Pomme du Sahel) thus providing sustainable alternative livelihoods for the rural populations including women (Output 4 – testing and promotion of alternative livelihood systems).

2.1.5 Projected potential impact

This technology has a lot of potential and can be up-scaled to wider geographical areas in the desert margins of sub-Saharan Africa.

2.2 Promotion of gum arabic (*Acacia senegal*)

In Burkina Faso, land degradation causes loss of biodiversity and poor soil fertility, which leads to low yields. The consequences of all these problems are that the farmers become poorer. It is therefore important to find alternative sources of income for the rural communities. Following some characterization studies, both biophysical and socioeconomic, undertaken by DMP Burkina, the recommendation domains were identified for promising technologies to alleviate these rural poverty. One such technology is planting of gum arabic (*Acacia senegal).* In collaboration with the Institute for Rural Development, DMP Burkina undertook to study the socioeconomic aspects of the gum arabic sector in Burkina Faso, its potential to generate income for the rural communities and any other issue related to the cultivation of gum arabic.

2.2.1 The basis of the technology's success

Gum arabic is a tree that is well adapted to the Sahelian conditions, as in Burkina Faso. *Acacia senegal* exists in Kaya and in Gourma and gum arabic is being traded in Dori. This tree provides fodder for animals and the gum has a high market value. It is nutritious for humans and is used for medicinal purposes. It has high nitrogen content and low in tannins, which makes it a good quality of forage. It is an excellent alternative source of income for the rural communities in the Sahel. One of the biggest advantages of this tree is that it produces leaves early thereby enabling farmers to have fodder for their livestock following the dry season.

2.2.2 How is it implemented?

In collaboration with the Institute for Rural Development, DMP-Burkina undertook to study the socioeconomic aspects of the gum arabic sector in Burkina Faso, its potential to generate income for the rural communities and any other issue related to the cultivation of gum arabic. The production of plants was done in collaboration with the departmental services of the Ministry of Environment, the development associations such as the Aid association in Yatenga in Ouahigouya, the rural communities and farmers' organizations (Table 8).

Table 8. Number of *Acacia senegal* seedlings produced and planted in 2005 by DMP-Burkina.

Organization/institution	Number	*Acacia senegal*
DRECV NORD	Planned/expected	3250
	Production	2250
	Planted	2000
AAY	Planned/expected	3250
	Produced	3650
	Planted	3600
DRECV SAHEL	Planned/expected	8000
	Produced	8000
	Planted	8000
DPECV BOULSA	Planned/expected	40000
	Produced	40000
	Planted	40000
TOTAL	**Planned/expected**	**54500**
	Produced	**53900**
	Planted	**53600**

DRECV = Direction Regionale de l'Environnement et du Cadre de Vie; AAY= Association Aide au Yatenga; DPECV = Direction
Provinciale de l' Environnement et du Cadre de Vie

2.2.3 Up-scaling the technology

Farmers have been planting trees for a long time, but there is very little success in reforestation due to the lack of accompanying measures such as protecting the young seedlings from damage by animals. Quite often farmers protect these young seedlings only if they see some immediate benefits from the products of the trees. Those farmers who are familiar with gum arabic do protect the seedlings, but in the villages where this tree is newly introduced there is a need to create awareness among the farmers of the values of *Acacia senegal* as an important alternative source of revenue.

2.2.4 Contribution to the overall DMP project goal and objectives

This technology contributes specifically to DMP-GEF project Output 4 on testing and promotion of sustainable alternative livelihoods and to Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems.

2.2.5 Projected potential impact

This technology has a high potential in alleviating rural poverty through income generation from the sale of gum arabic. Besides, fodder from *Acacia senegal* can be a valuable source of dry season feed for the livestock thereby leading to increased productivity.

2.3 Promotion of Pomme du Sahel *(Ziziphus mauritania)*

Combating land degradation and improving food security for the people in the Sahel region require that a diversification of production and cropping systems. The introduction of adapted fruit trees, with high yield and economic potential such as the improved *Ziziphus mauritania* or 'Pomme du Sahel' offers a good opportunity to diversify the systems.

2.3.1 The basis of the technology's success

Improved species used include Ben Gurion, Gola, Kaithali, Seb and Umran. The following factors contribute to the success of the technology:

- The agroclimatic conditions in Burkina Faso are conducive to the growth of the Pomme du Sahel, which thrives well under dry and hot weather conditions of up to 50°C;
- The presence of low lying areas, water ponds and dams for irrigation purposes;
- The possibility of growing crops in association as the Pomme du Sahel creates a microclimate that favors the growth of horticultural produce;
- Know-how regarding techniques of production of the local *Ziziphus mauritania* in home gardens in the Sahel;
- Availability of animal excretions for manure production and composting;
- Production of 7 kg of fruit during the first year of planting in the Sahelian region around November/December;
- The fruits of the Pomme du Sahel weigh about 20 g each, which is about 10 times larger than the fruits of the local *Ziziphus mauritania.* In addition these fruits are rich in vitamins A, B, and C and have very good organoleptic characteristics (perfume, taste).
- Increase of the income of the producers as 1 kg of the fruits of Pomme du Sahel can be sold for 500-700 Fcfa (1 to 1.5 dollars)
- There is a demand for the fruit in the local market while there are also good opportunities for the processing of the fruits, thereby improving the nutritional status of the people. There is also a market outlet with the paving of the roads Ouagadougou-Dori and Dori-Terra in Niger.

2.3.2 How is it implemented?

Tests were initiated on stations in 2003 with the planting of five cultivars under drip irrigation and using perforated clay pots. In farmers' fields, village plantations were established and were managed by farmers associations.

Some of the impacts already achieved include:

- Production of young plants through grafting by 20 trained producers.
- Income generation: As an example, one farmer who has three Pomme du Sahel trees in his African Market Garden in the village of Sampelga fetched 3 to 4 dollars per day in selling the fruits.
- Production of 1.28 t of fruits of Pomme du Sahel in the Katchari station with 195 trees in their 3rd year of production during the campaign 2005-2006.

2.3.3 Up-scaling the technology

The up-scaling strategy for this technology is based on training producers and sensitizing rural communities through:

- The use of mass media (local radios, national radios, national television, press, brochures), etc.
- Guided tours, open days, demonstrations, fairs and expositions, musical groups, t-shirts, fiche techniques
- Three types of training are provided to the farmers: i) techniques of harvesting and collecting seeds of local trees, pre-treatment, conservation of seeds and construction of nurseries; ii) techniques of grafting; and techniques of planting and maintaining the plants

Various stakeholders/partners are involved in these activities including government agencies, NGOs and research institutions.

However, there are some constraints to the implementation of this technology such as rodents, termites and insects that damage leaves and fruits. This requires some crop protection measures. In addition the technique of grafting is still not well known and there is a need to pursue the training of producers.

2.3.4 Contribution to the overall DMP project goal and objectives

This technology contributes specifically to DMP-GEF Output 4 on testing and promotion of sustainable alternative livelihoods and to Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems.

2.3.5 Projected potential impact

The introduction of adapted fruit trees, with high yield and economic potential such as the improved *Ziziphus mauritania* or 'Pomme du Sahel' offers a good opportunity to diversify the systems. In addition, 33,250 plants were expected to be produced and planted in six villages (Oursi, Banh, Bougou, Goroldbalé, Yakouta and Katchari).

Table 9. Summary of achievements by technology in 2005 in Burkina Faso.

Major intervention	DMP achievements in 2005	Targets involved	Partners' inputs
Management of degraded lands using the delphino plow, half-moons and seeding	• 320 ha were regenerated as follows: Banh 100 ha Tougouri 100 ha Dori (Katchari) 60 ha Oursi 60 ha • Restoration of herbaceous species and also the re-appearance of insects and termites that have beneficial effects on the soil fertility and structure	Local communities at DMP benchmark sites and around them	• Identification and choice of sites made by local populations • Rent of plows (by 'Project Front de Terre' and Operation Plan Acacia of the Ministry of Environment) • Monitoring by regional departments of the same Ministry
Promotion of gum arabic (*Acacia senegal*)	• 53,600 plants have been produced and planted with a density between 425 and 625 plants per hectare according to the area in villages	54,500 plants were expected to be produced and planted in six villages (Oursi, Banh, Bougou, Goroldbalé, Yakouta and Katchari)	• In collaboration with the Institute for Rural Development, the DMP undertook to study the socioeconomic aspects of the gum arabic sector in Burkina Faso, its potential to generate income for the rural communities. • The production of plants was done with the departmental services of environment, NGOs such as the Aid association in Yatenga in Ouahigouya, the rural communities

			and farmer's organizations. • Planting was done by farmers, who also ensure the protection of young seedlings.
Promotion of Pomme du Sahel (*Ziziphus mauritania*)	• Production of young plants through grafting by 20 trained producers • Income generation: For example, one farmer who has three Pomme du Sahel trees in his African Market Garden in Sampelga in village earned up to $4 per day by selling the fruit • Production of 1.28 t of Pomme du Sahel in the Katchari station from 195 trees in their 3rd year of production during 2005-2006 • About 26,915 plants were produced and planted	33,250 plants were expected to be produced and planted in six villages (Oursi, Banh, Bougou,Goroldbalé, Yakouta and Katchari)	• Various stakeholders/partners are involved in these activities including government agencies, NGOs and research institutions.

C. Senegal

1. The context

Land degradation constitutes a major constraint to agricultural production in the desert margins of Senegal. It leads to the loss of the biodiversity and to low yields of major crops as a result of low soil fertility. To arrest land degradation and thereby improve productivity of lands and conserve biodiversity various strategies and technologies are being implemented by DMP-Senegal. These include:

- The promotion of Pomme du Sahel;
- The establishment of African Market Gardens and home gardens;
- The establishment and management of the 'mis en defens' or protected areas of biodiversity and natural community reserves.

Other activities relate to the regeneration of mangrove and the establishment of the Sahelian Eco-Farm (SEF).

2. Description of the technology/strategy

2.1 Dissemination/promotion of 'Pomme du Sahel' or *Ziziphus mauritania*

Pomme du Sahel (*Ziziphus mauritania)* is an improved fruit tree, which has a lot of potential of providing nutritious fruits with high market value and can also be planted to restore degraded lands.

2.1.1 How is it implemented?

In Senegal this technology is being promoted using various mechanisms:

a) Production of plants 'porte greffe' or rootstock and 'parc a bois'
The rehabilitation of the nurseries of Hann, Nioro and Bambey enable the production of 350,000 rootstocks of *Ziziphus mauritania.* In 2006, approximately 600,000 plants will be produced.

b) Reconversion of local populations of Ziziphus mauritania
A reconversion of the local population of *Ziziphus mauritania* is done in home gardens and fields, fruit tree plantations and live fences to address the problem of the slow growth of *Ziziphus* rootstock and to enhance the dissemination of Pomme du Sahel. In the first instance, 120 plants, about 10 years old, were grafted using scions from six-year old trees.

The conversion of local *Ziziphus* using grafting directly on the branches of old trees could contribute to enhancing the dissemination of Pomme du Sahel. This technique is less complex and less costly compared to the production of plants in nurseries.

c) Building the capacity of the populations in the grafting techniques
The training of the rural communities in the techniques of grafting and production of *Ziziphus* contributes to enhancing the dissemination of Pomme du Sahel. Approximately 1000 plants of local *Ziziphus* were produced from 5 market gardens and 15 home gardens that are managed by women associations. In collaboration with the project "Forgin Link", plants that were produced were used for training purposes.

2.1.2 Up-scaling the technology

In up-scaling this technology, the local populations were trained in the techniques of grafting and production of *Ziziphus mauritania*. Several demonstrations were conducted to help farmers be familiarized with the grafting and planting of Pomme du Sahel. Various stakeholders/partners are involved in these activities including government agencies, NGOs and research institutions.

2.1.3 Contribution to the overall DMP project goal and objectives

This technology contributes specifically to DMP-GEF Output 4 on testing and promotion of sustainable alternative livelihoods and to Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems.

2.1.4 Projected potential impact

The introduction of adapted fruit trees with high yield and economic potential, such as the improved *Ziziphus mauritania* or 'Pomme du Sahel' offers a good opportunity to diversify the systems.

2.2. Promotion of African Market Gardens and Home Gardens

2.2.1 The basis of the technology's success

Home gardens are used to produce vegetables, legumes and fruits using wastewater and organic wastes from the houses as well as animal manure. They are also easily protected from damage by animals. They enable rural families to have a balanced diet and to generate additional income without major investments for fences, irrigation and fertilizers. They are very beneficial for women, who practice it the most.

2.2.2 How is it implemented?

The establishment of home gardens was done in collaboration with National Agricultural and Rural Advice Agences (ANCAR) and the L* Cadres Locaux de Concertation des Organasations Paysannes (L*CLCOP) of the rural community of Dya. The tests started in three villages, namely Dya, Keur Waly and Diokoul. About 15 home gardens here are being managed by women. Approximately 500 plants of *Moringa oleifera* (nebeday) and *Cajanus cajan* (pigeonpea) were intercropped with various vegetables such as eggplant, Hisbiscus, tomato and pepper.

As Table 10 below shows, the revenues generated from the sale of surplus production amount to about 40 dollars from five home gardens in the village of Dya, and 30 dollars in Keur Waly and Diokoul each.

The dissemination of the African Market Gardens is being done mainly by the pilot women associations of Dya and Djilass. The improvement of low lying areas offer opportunities to promote Market Gardens.

2.2.3 Up-scaling the technology

Up-scaling of the African Market Garden was done mainly through the participation of the women associations in Dya and Djilass, while that of home gardens was through the women in Dya, Keur Waly and Diokoul. This technology will be up-scaled to other communities in the country.

2.2.4 Contribution to the overall DMP project goal and objectives

This technology contributes directly to DMP-GEF Output 4 on testing and promotion of sustainable alternative livelihoods.

2.2.5 Projected potential impact

Home gardens and African Market Gardens particularly target women and the technology has great potential for increasing household income through the sale of the vegetables and improvement of household nutritional status through the consumption of these vegetables. This can in effect result in reducing pressure in harvesting wild plant species, thereby reducing biodiversity loss.

Table 10. Average production and income per village from home and African Market Gardens

Villages	Crops	Production (kg)	Cost (F CFA)	Revenues (F CFA)
Dya	Tomato	25	250	6250
	Egg plant	40	200	8000
	Pepper	75	1000	7500
Sub-total				**21750**
Keur Waly	Tomato	16.5	250	4125
	Egg plant	18	200	3600
	Pepper	8	1000	8000
Sub-total				**15725**
Diokoul	Tomato	21.25	250	5315
	Egg plant	17	200	3100
	Pepper	5.5	1000	5500
Sub-total				**14215**
Total revenue				**51690**

2.3 Management and improvement of mis en defens areas and natural community reserves

2.3.1 The basis of the technology's success

The main goal of this technology is the conservation of the forest ecosystems using a strategy of entrusting the rural populations with the responsibility of managing the forest and animal resources in their landscape in a rational manner. This is referred to as 'mis en defens'. This concept aims at restoring the vegetation and the socio-ecological equilibrium and at meeting the needs of the population for forest products. Through this concept of 'mis en defens' the rural communities agree on a number of regulations and procedures for the use of the products from these protected areas.

2.3.2 How is it implemented?

DMP Senegal provides the backstopping to these village groups in managing mis en defens so as to ensure sustainability of the operation in both ecological and socioeconomic aspects. At present 390 areas of mis en defens covering about 26,682 ha were established by the communities to regenerate the vegetation cover within the Project PAGERNA (Table 11). In the project PGIES, five natural community reserves were established.

The impacts achieved so far include:

- In the areas of mis en defens of Sambande, the use of products from these protected areas generate revenues of \$3000-4000 for women's groups in seven villages. The monetary value of what neighboring populations consume amounts to about \$5000.
- In the zone of Mbadakhoune, the revenues from the sale of forest products and honey were estimated at \$2000.
- The wood productivity of the area has increased while there is the regeneration of rare species and reappearance of lost species such as *Nauclea latifolia, Grateova religiosa, Combretum lecardii, Ficus iteophilla, Grewia bicolor, Mitragyna inermis* and *Fagara xanthoxyloïdes.*
- The Natural Community Reserves of Sambande and Mbadakhoune sites have contributed to the improvement of medicinal plant species with about 87 and 60 species respectively.

• The re-appearance of some wild animal species is also a very positive impact.

Table 11. Areas under mises en défens

Rural communities	Area under mises en défens (ha)	Number of villages	Number of people	Management plans and DMP contribution
Dya	1318	30	19,778	One plan to implement socioeconomic monitoring and evaluation
Paoskoto	4864	132	39,071	Elaboration and implementation of management plan: socioeconomic monitoring and evaluation
Keur Baka	2941	62	17,398	Management plan to develop: socioeconomic monitoring and evaluation
Mbadakhoune	873	29	11,952	Management plan to develop: Socioeconomic monitoring and evaluation

2.3.3 Up-scaling the technology
This technology will be up-scaled to other communities in the region of Fatick. DMP-Senegal will facilitate the establishment of these mis en defens in other sites and provide the necessary technical backstopping.

2.3.4 Contribution to the overall DMP project goal and objectives

This technology contributes specifically to Output 1.7 on identification and enhancement of local knowledge related to the preservation and restoration of biological diversity and to Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems.

2.3.5 Projected potential impact

This technology has a great potential for restoring the vegetation and the socio-ecological equilibrium of biological diversity and at the same time meeting the needs of the populations for forest products.

2.4 Sahelian Eco-Farm (SEF)

2.4.1 The basis of the technology's success

The Sahelian Eco-Farm (SEF) is an integrated production system for soil, water, crop and nutrient management for increased productivity. It consists of water harvesting techniques (half-moons), the growing of high value trees such as Pomme du Sahel and *Acacia colei*, which provide food for human consumption, fodder and feeds for livestock and chicken, mulch to protect the soil, the rotation of cereals and leguminous crops and various cultural practices for improved water and nutrient management.

2.4.2 How is it implemented?

A SEF was installed in Pelew. At present, other sites and farmers associations are being identified for the establishment of the SEF in their fields.

2.4.3 Up-scaling the technology

DMP Senegal is involved with 20 rural communities in its efforts to scale-up this technology. The local plans of development serve as a basis for the scaling-up activities. These activities integrate aspects of natural resource management, livestock and socioeconomic issues. There are various forums for interactions and discussions with the rural communities, which ensure the participation of vulnerable populations in all the activities. The management and use of the natural resources are decentralized.

2.4.4 Contribution to the overall DMP project goals and objectives

This technology contributes to the overall goal of the improvement of the food security and income of rural communities. It also contributes specifically to DMP-GEF Output 4 on testing and promotion of sustainable alternative livelihoods and to Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems.

2.4.5 Projected potential impact

• Improvement of food security and reduction of poverty;
• Restoration of vegetation cover and rehabilitation of degraded lands;
• Strengthening of 20 rural communities.

Table 12. Summary of achievements by technology in 2005 in Sénégal

Major intervention	DMP achievements in 2005	Targets involved	Partners' inputs
1. The promotion of Pomme du Sahel	• Producation of 250 000 plants of pomme du sahel as scions • Creation of wood parks for the production of grafts • Setting up of 20 fruit orchards for the production of improved ziziphus by local 'jujubiers surgreffages' • Production of 50 000 improved ziziphus • Spread of 1500 pomme du sahel in African Market Gardens	20 farming communities within the DMP target zone	• Rehabilitation of three village nurseries • Identification of pilot farmers with the support of the National Agricultural and Rural Council of the Ministry of Agriculture • Contribution to the production of 50000 plantations of root stocks of ziziphus by the forest service (Ministry of Environment) in nurseries of Kaolack, Thièses and Faticks • Production of 1000 plantations of ziziphus by women groups of Dya
2. The establishment of African Market Gardens and home gardens	• Dissemination of home gardens • Dissemination of African Market gardens with the pilot women groups of Dya and Djilass	• 38 home gardens have been established in three farming communities integrating plantations of *Moringa oleifera*, *Cajanus cajan* and vegetable crops; these home gardens provide incomes of \$100 to 105 per season on 300 sq m • Five African market gardens in the farming communities of Dya, Thiombies and Ngandas	• Identification of the pilot women groups with the support of the ANCAR of the Ministry of Agriculture • Contributions of ONGS team Sahel 3000, team ANCAR and partners in rehabilitation of sites, follow-up and team assessment of activities
3. The establishment and management of areas of biodiversity and natural community reserves	• Development and implementation of management plans for sustainable ecological, socioeconomic and cultural advantages of protected areas in Dya, Sambandé, Paoskoto, Keur Baka and Mbadakhoun • Establishment of four protected areas covering 3300 ha	• 9996 ha under mises en défens targeted with concerted and consensual management • 3300 ha of protected areas integrated • In Sambandé local people earn \$5000 from produce; • The use of non-shrub products women groups incomes of \$3000-4000 a year	• The Ministry of Environment and different partners (ONGS, local groups) contributed to the identification of sites, facilitation and set up of strategies, management, follow-up assessment as well as backing of local actor capacities

D. Mali

1. The context

Land degradation constitutes one of the major constraints to food production in the desert margins of Mali. Water and wind erosion contribute to exacerbate the problems of land degradation, in addition to climate variability and anthropogenic factors (overgrazing by animals, deforestation, inappropriate land management practices. To alleviate these constraints, DMP Mali works closely in collaboration with various development and government agencies in assessing ecosystems dynamics and in implementing strategies for combating land degradation and conserving biodiversity. Improving the livelihoods of the people living in the desert margins of Mali is also one of the major goals of DMP Mali.

2. Description of the technologies/strategies

The best-bet technologies for arresting land degradation and conserving biodiversity that are being promoted by DMP Mali include the African Market Gardens using drip irrigation, the dissemination of Pomme du Sahel (*Ziziphus mauritania)*, and planting of eucalyptus. These different technologies contribute to diversify the production system, enhance carbon sequestration and improve the income of the farmers in the Gao region.

2.1 African Market Gardens using drip irrigation

2.1.1 The basis for the technology's success

African Market Gardens is a technology to diversify production systems and provide alternative means of livelihoods for rural communities and vulnerable groups, especially women. It enables rural families to have a balanced diet and to generate additional income without major investments in fences, irrigation and fertilizers. The technology is very beneficial for the women who practice it the most. African Market Gardens also provide a means to fight against erosion which affects the northern regions of Mali.

The drip irrigation system with low pressure has been installed on a hectare of land. Vitro plants date palms and grafted *Ziziphus mauritania* were planted under this drip irrigation system. A water tank/reservoir was installed to meet the water requirements of the plants and to reduce costs of irrigating these plants. Water is supplied to the tank/water reservoir using a water pump. Drip irrigation is based on the delivery of water in small quantities right where the plant needs it, thereby increasing water use efficiency and reducing quantity and costs of water used.

2.1.2 How is it implemented?

Twelve women and men associations in Tacharane were trained in the techniques of establishing the drip irrigation system in the farmers' gardens. This was done in collaboration with NGOs. Technicians will also receive additional training on this technology. These technicians will be trainers of other users of the systems.

In May 2005, a guided visit was organized to present the achievements of the DMP project to the administrative authorities, policy makers and technicians in the region. Regional technical services (extension agents) and farmers also took part in this visit.

In July 2005 the Hon. Minister of Agriculture of Mali, during his mission to Gao region, also visited the DMP site at Bagoundié. Impressed with African Market Garden technology, he recommended a large diffusion of this technology to other regions in northern Mali. His Excellency, the Prime Minister of Mali also visited the Bagoundié site and also recommended a large diffusion of African Market Garden technology as means of alleviating poverty in the northern region of the country.

2.1.3 Up-scaling the technology

Many women and men associations are involved in the up-scaling of the technology. For a large diffusion of the technology, a week of local users of research outputs was organized in June 2006 with the support of the National Committee of the Agricultural Research of Mali. This week of exhibitions of technologies from research involved 120 representatives of the agricultural technical services, NGOs, farmers and regional administrative authorities. The technology on African Market Garden with drip irrigation was displayed and demonstrated to visitors. Following this week of exhibition, some units of the technology have been ordered from ICRISAT-Niamey and distributed in the northern region of Mali in collaboration with NGOs and extension services. The technology will be up-scaled to other northern regions of Mali (Tombouctou and Kidal) in DMP Phase 3.

2.1.4 Contribution to the overall DMP project goals and objectives

The African Market Garden using drip irrigation contributes to the restoration and conservation of biodiversity through the diversification of crops (Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems). It also enables the diversification of income sources and helps to reduce poverty (Output 4 on testing and promotion of sustainable alternative livelihoods).

2.1.5 Projected potential impact

The African Market Garden will be disseminated in at least 25 households, 20 women gardens and 10 youth gardens.

2.2. Dissemination of Pomme du Sahel or *Ziziphus mauritania*

The improved *Ziziphus* is a plant commonly used by the northern population of Mali for different needs (human consumption of the fruits, use of the leaves, roots and tree bark for as medicine and leaves as livestock feed). The improved *Ziziphus* also constitutes a source of diversification of cultures and incomes.

2.2.1 The basis for the technology's success

The cultivars of Pomme du Sahel that are used include Gola, Seb, Umuran, Ben Gurion, and Katle. During the months of October 2005 to January 2006, scions were collected and grafting was done.

Fruits of *Ziziphus mauritania* are consumed by the people in the northern part of Mali as a part of their regular diet. The large size of the fruits is a major factor that enhances the adoption of the technology.

2.2.2 How is it implemented?

Various meetings were held between DMP Mali and its partners for the purpose of sensitization. Guided tours of the nurseries were also conducted in CRRA of GAO and the Bagoudje station for partners. Training courses were given on grafting techniques and nursery management. DMP Mali also trained students in agroforestry technologies (grafting of Pomme du Sahel) in collaboration with Centre Régional de Recherche Agronomique (CRRA) of GAO and the Professional Center of training for the promotion of Agriculture in the Sahel (CFPPAS). Partners include NGOs and development agencies.

Field days were organized for producers and extension agents. Training in agroforestry technologies were also organized in collaboration with the International Center for Research in Agroforestry (ICRAF) Samanko (Mali) on grafting techniques.

2.2.3 Up-scaling the technology

This technology is up-scaled mainly through training of partners and rural communities in grafting techniques and demonstrations. Different agreements have been signed by DMP Mali with many NGOs partners for a large diffusion of the technology. In addition, women associations were formed in Bagoundié and Berrahs for grafting of improved *Ziziphus* and for establishment of small plantations as means of additional income. During Phase III of the project, the improved *Ziziphus* will be distributed in all northern regions of Mali such as Tombouctous and Kidals in view of their request for the technology.

2.2.4 Contribution to the overall DMP project goals and objectives

The dissemination of Pomme du Sahel contributes to the restoration of biodiversity and the diversification of income of the producers as well as reducing poverty (Output 4 on testing and promotion of sustainable alternative livelihoods).

2.2.5 Projected potential impact

• 240 households, 8 farmers groups/associations and 500 women benefited from the technology.
• 200 producers were trained in agroforestry technology and grafting techniques.
• Significant increase in the income of producers.

2.3 Rehabilitation of degraded lands and carbon sequestration: Eucalyptus plantation

2.3.1 The basis for the technology's success

The objective of planting eucalyptus is to rehabilitate degraded lands, provide fuel wood and it is used for medicinal purposes in the northern part of Mali.

One of the main constraints in the northern regions of Gao is the lack of sufficient fuel wood and construction materials. The wood used primarily for construction is from eucalyptus. It provides an important source of revenues to villages that have plantations.

This is the main incentive for rural communities to plant this variety. Eucalyptus is planted along the river banks and in the Niger Valley. Planting along river banks is a technique for protecting crops from sand dunes and blast. It also serves to enhance carbon sequestration and restore soil fertility.

At present more than 10 hectares of plantations of eucalyptus are established in the valleys and along the river Niger. Interviews with farmers indicate that 3.5 m of eucalyptus are sold for US$8, which increases farmers' income. Its use for medicinal purposes such as treatment of cough and stomachache was also highlighted by farmers.

During the workshop on agroforestry technologies for producers organized in Gao between 12-14 July 2006 by DMP Mali and ICRAF Samanko, participants revealed that a hectare of eucalyptus plantation is more profitable than a hectare of rice.

2.3.2 How is it implemented?

DMP Mali works with private nursery agents to produce plants to meet the needs of the various partners. Most of the work is done in collaboration with NGOs and various associations of producers. This participatory approach enables the involvement of the rural populations who take care of the plantations, and protection against damage by animals and their management. NGOs and technical service units trained farmers in establishing and managing these nurseries. Seeds of trees and plastic pots are distributed to the partners based on their needs.

2.3.3 Up-scaling the technology

In order to ensure a large diffusion of this technology very appreciated by the population, collaboration agreements have been signed between DMP-Mali, the NGOs and technical partners. Agroforestry workshops were organized in collaboration with ICRAF (2004 and 2006) so that producers can master techniques of production and plantation of eucalyptus better. Other contracts of collaboration will be signed between DMP-Mali, populations, the NGOs, the technical services in the DMP Phase 3 to continue the up-scaling of the technology.

2.3.4 Contribution to the overall DMP project goals and objectives

The plantations of eucalyptus contribute to the restoration of biodiversity and to the rehabilitation of degraded lands (Output 2 on development and implementation of strategies for conservation, restoration and sustainable use of degraded agro-ecosystems). They provide fuel wood and construction materials, diversify and increase the income of rural communities (Output 4 on sustainable alternative livelihoods).

2.3.5 Projected potential impact

Approximately 30 farms and 10 villages are involved in this activity. Soil fertility is improved. The income of rural communities is increased.

Table 13. Summary of achievements by technology in Mali in 2005

Major intervention	DMP achievements in 2005	Targets	Partners' input
1. African Market Gardens using drip irrigation	• Twelve women and men's associations trained in the use of drip irrigation system in farmers' gardens		
2. The dissemination of Pomme du Sahel (*Ziziphus Mauritania)*	• 240 households, 8 farmers groups/associations and 500 women benefited from the technology • 200 producers planted improved cultivars of Ziziphus mauritania	• Partners trained in grafting techniques • Significant increase in the income of producers • Contributed to the restoration of biodiversity	• Field days organized for producers and extension agents • Training in agroforestry with ICRAF on grafting techniques
3. Rehabilitation of degraded lands; Eucalyptus plantation	• 30 farms and 10 villages are involved in this activity • Establishment of nurseries • Distribution of seed and young plants to partners	• Soil fertility has improved; • The income of rural communities has increased rehabilitation of degraded land • Fuel wood has increased; carbon sequestration has improved	• Various training and workshops organized

Conclusion

Major conclusions drawn from the implementation of best-bet technologies in the nine DMP countries are:

- Combating land degradation and conserving biodiversity in the Desert Margins of sub-Saharan Africa requires diversification of production and cropping systems. Hence, technologies that provide alternative livelihood options to the local communities are essential to the success of land degradation control measures.
- Technologies which have obvious and immediate benefits to communities are more readily accepted and adopted. This is illustrated by the reported increased income generation from technologies such as African Market Gardens in Mali and Senegal, beekeeping and honey production in Kenya, fodder conservation for sedentary livestock herds in Kenya, processing of Mopane worms in Zimbabwe and Pomme de Sahel in Burkina Faso, Mali and Senegal.
- Many hectares of degraded lands and rangelands have been reclaimed through various land degradation control technologies in countries such as Burkina Faso, Niger, Kenya, South Africa and Zimbabwe.
- Land ownership is critical to farmers' investment in land degradation control and better rangeland management strategies. Policy advocacy in DMP Phase 3 will be necessary to promote land ownership by rural communities hoping that this will lead to greater adoption of some of the best-bet technologies that address land degradation control.
- Many stakeholders (farmers, women, technicians) have been trained during the implementation of the best-bet technologies in all the countries. Training provided include grafting techniques, use of drip irrigation for African Market Gardens, community based monitoring and assessment of rangelands, use of LLM and FIRM.
- Community-based natural resources management is key to sustainable resource use and derivation of benefits by the local community. A good example to illustrate this is community reserves' mis en defens in Senegal, which is being managed by the local community and about $4000 was realized as extra income from the sale of forest products and other resources from the reserves.
- Sustainability of some of the technologies especially tree planting and reseeding of rangelands depends heavily on rainfall, which is often erratic in many DMP countries.
- High cost of scaling up some of the technologies, especially those that concern rehabilitation of degraded lands is a major constraint to large-scale dissemination of these technologies. For example rehabilitation of degraded lands using delphino plow in Burkina Faso cost $95 per hectare, which is far beyond what a local community can

afford. Another constraint to rehabilitation of degraded lands by tree planting and pasture production is protection of the land being reclaimed from livestock grazing, especially if it is communally owned.

- Many of the technologies implemented have great potential to arrest land degradation and biodiversity loss in the Desert Margins of sub-Saharan Africa. However, larger scale up-scaling of these technologies will necessitate influencing policy in the respective countries, which will be the main thrust of project implementation in DMP Phase 3.

Capacity of stakeholders and target populations enhanced (capacity building)

Initiatives undertaken in 2005 at project sites were planned to encourage the development of (as opposed to the modification of) new rural enterprise and livelihood ventures. Both Kenya and Burkina Faso have begun to promote alternative rural enterprise, by making rural credit available to provide seed finance for new ventures, renewable sources of energy for rural initiatives, and business development support for new enterprises. In Senegal activities focused on the domestication of wild fruit, for commercialization.

Over the last year a range of capacity building activities have been undertaken with DMP stakeholders. Training needs were first assessed and prioritized in order to tailor training activities to users' needs. For example, ICRAF is finalizing their report on a workshop entitled 'Agroforestry in the Sahel: present status, needs and perspectives' during which training needs were identified in close consultation with the major players in West and Central Africa. CIRAD has circulated a survey questionnaire to all DMP partners asking about their training needs in terms of capacity/governance building for Natural Resource Management. The focus will be on environmental, socio-economic and policy evaluation. This will strengthen local capacity for evaluating NRM options and policies, and for devising policy scenarios. This would also strengthen the capacity of NARS scientists to estimate the economic impact of a given technology and fine-tune their interventions accordingly.

Since Phase II focused on technology dissemination, TSBF-CIAT/AfNET, in collaboration with DMP, organized a training workshop to create awareness and develop researchers' skills in farmer-participatory research and scaling-up of promising innovations. DMP partners from Burkina Faso, Kenya, Niger, Senegal, South Africa and Zimbabwe attended. Partners from Burkina Faso, Kenya, Niger and Senegal also participated in a training workshop on 'Assessing crop production, nutrient management, climatic risk and environmental sustainability with simulation models'. They familiarized themselves with DSSAT (Decision Support System for Agrotechnology Transfer), a comprehensive computer model for the simulation of crop growth and yield and plant water, nutrient and carbon dynamics. IFDC organized a training workshop for 350 pilot-farmers and 50 national extension agents from Burkina Faso on large-scale dissemination of Integrated Soil Fertility Management technologies. Another IFDC workshop on 'CASE' and technical options for cropland forage production was attended by 50 participants in Burkina Faso. CASE promotes commodity chain development and the agro-input sector. DMP-Niger scientists took part in a training course on monitoring and impact studies of projects in Segou, Mali.

In the area of postgraduate training, students from the University of Niamey worked on their MSc theses on documentation of indigenous knowledge of livestock genetic diversity in south-western Niger under the supervision of DMP-ILRI scientists.

DMP has also undertaken in-country and cross-country training activities. Scientists from South Africa attended a training workshop in Namibia, organized by the DMP-Namibia. They acquired hands-on experience of the FIRM (Forum for Integrated Resource Management) and the Local Level Monitoring (LLM) programs that are used by the DMP in Namibia. A PhD student from DMP South Africa visited Burkina Faso, Mali, Niger and Senegal to document and evaluate restoration and NRM technologies in these countries. DMP South Africa also supported training and capacity building workshops for farmers and the youth of formerly disadvantaged schools in the Mier target area in the Kahalari. In addition small livestock breeding and management training courses were given to farmers and land users in the Mier region. DMP South Africa has developed a training manual for production of organic *Rooibos* seedlings. Through training (technical and institution-building) at grassroots level, the capacity of resource users and service providers to sustainably manage their natural resources was enhanced. In Mali several women were trained in tree grafting and management of nurseries. In Burkina Faso, 48 farmers from 15 villages in the department of Banh were trained in grafting and production of Pomme du Sahel" and in the use of drip irrigation. In Senegal producers were trained in the techniques of grafting *Ziziphus mauritania.* In Niger, tourist guides were trained and provided with tourist maps. IRD has provided training to DMP Burkina partners in microbial ecology.

ICRISAT carried out a number of field trainings during the year. A nursery-training course was held at ICRISAT, Sadore for 36 farmers from Burkina Faso, Mali and Niger. A course on modern production techniques of fruit trees was given to 30 producers in Bobo Dioulasso, Burkina Faso. A course on multiplication and storage of vegetable seeds was given to 40 practitioners from the DMP countries in West Africa. Four tree-grafting courses with emphasis on the grafting of Pomme du Sahel plants were given to 120 farmers. About 400 farmers from Burkina Faso, Ghana, Senegal, Gambia, Guinea Bissau, Mauritania, Mali, Niger and Chad were trained on installation, operation and maintenance of African Market Gardens. Forty farmers from Burkina Faso and Ghana participated in a two-day course on the principles and operation of the Sahelian Eco-Farm. Three scientists from DMP-Kenya were trained at Sadore for a period of three months on tree grafting, African Market Garden, and other relevant technologies.

Priority 5a: Science and technology policies and institutions

Output 8C. Policy briefs and policies facilitating the uptake and upscaling of NRM and intensification/ diversification technology options and enhancing the conservation of biodiversity and reducing land degradation with associated capacity building measures devised and promoted in SSA by the end of the DMP Phase II in 2009 and knowledge shared annually

MTP Output Targets 2006:
Policy brief on institution linkages facilitating the uptake of NRM and intensification/diversification prepared and disseminated

Contribution to the UN FCCC by RSA.

Policy advocacy efforts on the conservation of biodiversity and reducing land degradation completed in at least 9 countries in SSA

Contributions to the National Action Plans of the UNCCD in SSA.

In West and Central Africa (WCA), efforts were made by DMP partners to document exiting policies, through literature review and secondary data collection. In general, policy guidelines follow the general framework of the decentralization process that is being implemented in the four countries. More authority is being given to local and communal structures in managing natural resources

In East and Southern Africa (ESA) a series of studies were initiated with country partners, illustrating the impact of different environmental and agricultural policies in various cross border locations in the ESA region using remote sensing techniques. This work will continue and also be incorporated in country level policy debate. With partners in west Africa this work may be extended to include similar analysis there.

Sound policy interventions/guidelines for sustainable resource use formulated, adopted and implemented (policy and legal framework)

The Kenya government is in the process of developing a policy for the Arid and Semi Arid Lands (ASALs). Various consultative meetings in which members of the DMP have participated have been held. The National Policy for Development of the ASAL areas of Kenya was prepared in 1992 and the government in collaboration with UNDP is currently updating and reviewing the document. Discussions have been held between stakeholders; and an expert workshop and two regional workshops have been held and the output incorporated in a draft national policy in Dec 2003. The document has been forwarded to the Kenya government for ratification and implementation. A second policy document known as the Soil Fertility Initiative for Kenya has been prepared. Discussions have been held between stakeholders; several expert workshops have been held and the output incorporated in a draft national policy.

In all the four countries in WCA, efforts were made by DMP partners to document exiting policies, through literature review and secondary data collection. In general, policy guidelines follow the general framework of the decentralization process that is being implemented in the four countries. More authority is being given to local and communal structures in managing natural resources.

DMP Namibia contributed to a study to assess to what extent the current policy, legislative and planning framework is conducive to the implementation of better land management, particularly biodiversity conservation and combating of desertification. Since the 1996 policy analysis, there have been many positive changes to the policy environment. Several environmental policies that reflect global thinking regarding sustainable natural resource management and utilization (guided largely by the principles enshrined within the UNCCD, UNCBD and other agreements), have been formulated. Favorable sustainable development statements now appear in many other sectoral policies. The Namibian DMP team contributes continuously to these developments. A comprehensive analysis of policies concerned with environmental issues has been summarized in CD-Rom format in South Africa. This will be updated again during 2005.

The DMP coordinator in ESA initiated a series of studies with country partners, illustrating the impact of different environmental and agricultural policies at various cross border locations in the ESA region using remote sensing techniques. This work will continue and also be incorporated in country level policy debate. With partners in West Africa this work may be extended to include similar analysis there.

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 of the semi-arid tropics of Africa and Asia

System Priority 4: Poverty alleviation and sustainable management of water, land and forest resources

Priority 4A, Specific goal 1: Develop analytical methods and tools for the management of multiple use landscapes with a focus on sustainable productivity enhancement
Priority 4D, Specific goal 8: Identify social, economic, policy and institutional factors that determine decision-making about managing natural resources in intensive production systems and target interventions accordingly

Output 9A. New tools and methods for management of multiple use landscapes and climatic variability with a focus on sustainable productivity enhancement, developed and promoted in collaboration with NARES partners in Africa and Asia

Output target 2007: Pilot projects on the demonstration and evaluation of integrated climate risk management and carbon sequestration initiated and underway with at least 8 carefully selected agricultural investor stakeholders in the Global SAT.

Table 9A.1 summarizes the 'Climate variability and change projects' that ICRISAT staff in Africa and Asia are currently involved in, or have developed over the last 12 months, and will be funded in 2007. During 2005 and 2006 ICRISAT , together with stakeholder partners, received donor support for the initiation of 6 pilot climate risk management/carbon sequestration projects in Africa which covered the countries, Cape Verde, Ethiopia, Gambia, Ghana, Kenya, Madagascar, Mali, Mozambique, Niger and Senegal. Furthermore, during 2006, ICRISAT and partners were successful with the submission of 5 competitive grant concept notes and have been invited to develop full proposals. One is to be funded by the African Development Bank through ASARECA and covers Sudan, Eritrea and Uganda with capacity building activities throughout ECA. Three are to be funded by IDRC / DFID through their 'Climate Change Adaptation in Africa (CCAA) grants scheme and cover Zimbabwe, Zambia, Ghana, Mali, Niger, Tanzania, Kenya, Ethiopia Eritrea and Sudan. The fifth will be funded by IDRC through their Research in Tobacco Control (RITC) Programme and will focus on Malawi.

In Asia over the same period six concept notes have been developed and two have moved forward to full proposal development (Table 9.1)

Table 9A.1. Climate variability and change projects in which ICRISAT is currently involved in Sub-Saharan Africa and Asia. (2005-2006). The Project Lead Centre (LC) is identified

Project Title	Consortium Members	Stakeholders and Project Partners	Countries involved	Project Status
Funded and Operational				
"Making the best of climate: Adapting agriculture to climate variability"	ICRISAT, IRI	Univ. Nairobi (LC), KMD, ICPAC, EARO, FOFIFA, SOMEAH.	Kenya, Madagascar, Ethiopia	Funded by, ASARECA-CGS **US$ 504,000**
"Options for improved use of climate knowledge and technology in the southern rangelands of Kenya."	ICRISAT **(LC)**, CIAT, IMTR	District Forest and livestock Office and extension staff at Makueni, Kenya. KMD, KARI	Kenya	Funded by DMP **US$ 40,000**
"Providing climate-based decision support for farmers and agricultural concession companies in Mozambique"	ICRISAT (LC), CIAT, ICRAF, Reading Univ.	Mozambique Leaf Tobacco, CIP, DPA, IIAM, EMPRENDA Alliance, USEBA, SNS and Mozambique Met. Service.	Mozambique	Funded by PROAGRI-MINAG (World Bank) **US$ 450,000**

Project Title	Consortium Members	Stakeholders and Project Partners	Countries involved	Project Status
"An aflatoxin risk early warning system to improve nutrition, health and income in West African smallholder farms"	ICRISAT, Agrhymet	ICRISAT **(LC)**, Agrhymet, IER, SARI, U. Sherbrooke, U. Florida	Ghana, Mali, West Africa	Funded by CIDA-CCLF **US$ 200,000**
"Measuring and assessing soil C sequestration by agricultural systems in developing countries – West Africa component"	ICRISAT	U. Florida **(LC)**, U. Hawaii **(LC)**, ICRISAT, ILRI, IER, SARI, ISRA, NARI	Cape Verd, the Gambia, Ghana, Mali, Senegal	Funded by USAID/SM-CRSP **US$ 2,000,000**
"Assimilation of very high resolution imagery for soil C accounting in Sudanian cropping systems: developing methods to reduce uncertainty in remote sensing estimates of system states"	ICRISAT	ICRISAT, IER **(LC)**, ISRA, SARI	Ghana, Mali, Senegal	Funded by TWNSO ***US$ 30,000***
Accepted for Full Proposal Development				
"Legume diversification in tobacco systems. Climate risk and market opportunities"	ICRISAT, Reading University	NASFAM (LC), Malawi Met. Services	Malawi.	CN accepted by IDRC-RITC, Full proposal developed and under review. **CD$300,000**
"Managing uncertainty: Innovation systems for coping with climate variability and change"	ICRISAT **(LC),** CIAT, ICRAF, Reading Univ.	ASARECA Networks, ILRI, ARC-Sudan, Univ. of Asmara, NARO-Uganda.	Sudan, Eritrea, Uganda and ECA	Under final review by ASARECA-CGS **US$ 658,000**
"Building adaptive capacity to cope with increasing vulnerability due to climatic change"	ICRISAT, CIAT and ZMD	Midlands State University, **(LC)** CARE, Dunavant Cotton, CSIRO, AREX, ASP	Zimbabwe and Zambia.	CN accepted by CCAA. Full Proposal under development **CD$ 1,084,600**
"*Managing risk, reducing vulnerability and enhancing productivity under a changing climate"*	ICRISAT, ASARECA-SWMNet.	Sokoine University of Agriculture, Tanzania. **(LC)**	Tanzania, Kenya, Ethiopia, Eritrea, and Sudan	CN accepted by CCAA, Full Proposal under development. **CD$ 1,085,000**
"Clues From The Landraces – positioning local knowledge on plant management of climate uncertainty at the heart of adaptive agricultural strategies"	ICRISAT, Agrhymet	ICRISAT (LC), Agrhymet, CIRAD, IER, SARI, IUCN, AMEDD, U. Sherbrooke, Ouranos Consortium, U. Florida	Ghana, Mali, Niger, West Africa	CN accepted by CCAA, Full Proposal under development. **US$ 1,045,000**
Assessment of Climate Change Impacts and Development of Adaptation Strategies for Rainfed Cropping Systems in Peninsular India	ICRISAT	IITM, APAU, UAS, Dharwad	India	Ministry of Environment and Forests, Government of India **Rs.218 lakhs**

Project Title	Consortium Members	Stakeholders and Project Partners	Countries involved	Project Status
Climate Change / Variability and Rural household strategies to adapt to them in the Semi-Arid Tropics (SAT)	ICRISAT/CRIDA	Farmers, Government departments, Non-Governmental organizations, and R&D institutions	India	Submitted to GEF **US1,000,000**

Output target 2007: 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.

Unique combinations of external and internal forcings make West Africa one of the most climatically sensitive regions worldwide, and perhaps the most challenging to model. Linkages between local climate and relatively predictable ocean drivers are less clear-cut and strongly modulated by intricate effects of continentality. This has translated into high, distinctive seasonal climatic uncertainty, in terms of the onset and the end of the rainy season (Figure 9A.1).

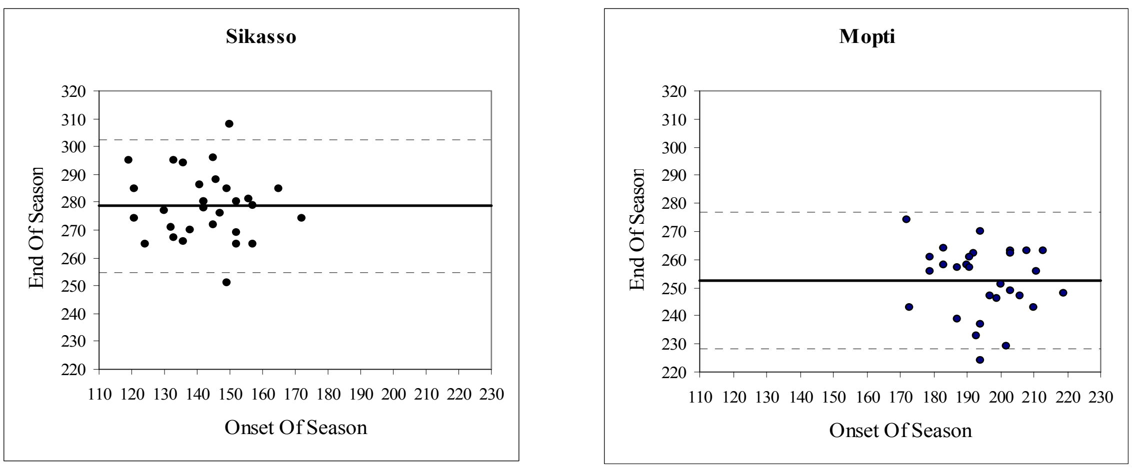


Figure 9A.1 Relationship between onset and end dates of the rainy season for Sikasso (northern guinea zone, 11°21'N) and Mopti (sahelian zone, 14°31'N). Normal period: 1971-2000. Average end date is highlighted by continuous line with ± 2 standard deviations (dashed lines).

Plants and farmers have selected singular adaptation traits to evade this constraint. They have become experts in resilience, consolidating West Africa into a primary center of biodiversity for sorghum, millet and other crops, handling the stochasticity of climate, and managing their way out of dramatic droughts as in the 1970s/80s.

Lately, modern climate science has worked to push back the frontier of rainfall predictability, but skill remains modest at various timescales contrasting with other regions of Africa and the world. Successful application of seasonal forecasts in sudano-sahelian smallholder agriculture appears today premature in a context of limited climate predictability, human vulnerability, and decision capacity.

Prospects will improve over the next decade, driven by improvements in coupled land-atmosphere models, population growth and intensified production systems (Figure 9A.2). Meanwhile there is scope for further preparatory work to adapt crop models to local farming systems, couple them with GIS technologies to target regional breeding programs, and invigorate early agrometeorological crop yield assessment using near-real time data assimilation methods. Progress is still required on these fronts to assess the profitability of potential response farming options and the sustainability of existing and alternate adaptation strategies in a context of global and regional change (Figure 9A.3).

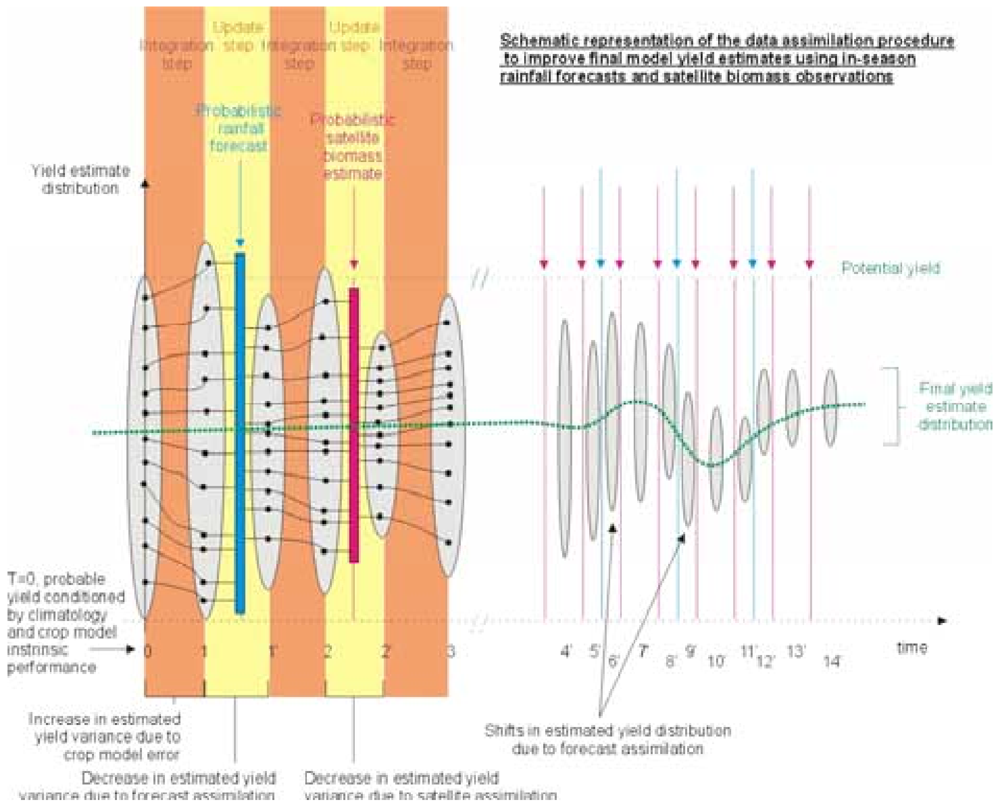


Figure 9A.2. Schematic representation of a data assimilation procedure to improve final model yield estimates using in-season rainfall forecasts and satellite biomass observations. At T=0, a crop model (mechanistic or empirical) is initialized with an ensemble of equally likely conditions (using a Monte Carlo technique). The model is then propagated forward in time with each realization of the ensemble. When estimates of system states (e.g. biomass), model parameters (crop type, sowing date,…) or boundary conditions (cumulative rainfall) become available an Ensemble Kalman Filter (EnKF) updates these and the measures of uncertainty thereof. EnKF has improved early estimates of system states in physical oceanography, meteorology, air pollution monitoring, hydrological streamflow forecasting, petroleum engineering, fish stock assessment, and more recently carbon sequestration studies (Jones et al., 2005)

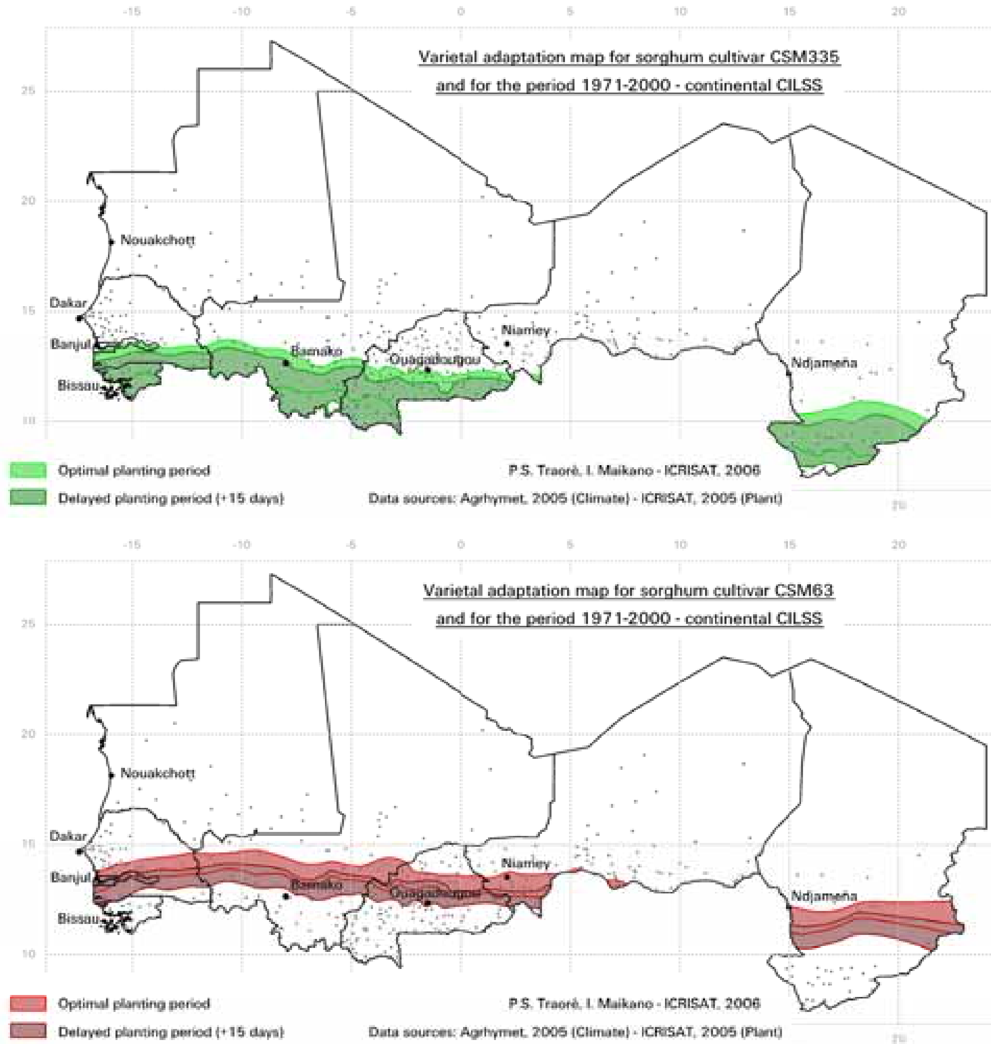


Figure 9A.3 Varietal adaptation maps for cultivars CSM335 (a) and CSM63 (b) and for the 1971-2000 period (continental CILSS countries). Here, adaptation is defined based on phenology, i.e. when the average flowering date occurs 20 (±10) days before end of season. End of season occurs when a moving 10-day average of daily rainfall drops below the ETP line (~end of humid period, adapted from Cochemé and Franquin, 1967). The two planting periods: optimal (shortly after onset of humid period) and delayed reflect the traditional spread of sowing dates. The adaptation strip for early-maturing, non-PP sensitive CSM63 is thinner than that of late-maturing, PP sensitive CSM335 on any given date. It rapidly migrates southwards for delayed sowing, with relatively small latitudinal overlap for a 15-day delay, in contrast to CSM335. CSM63 can be seen as a variety of large geographic adaptation if, and only if, there is a shift in sowing dates. CSM335 demonstrates both large temporal adaptation (small latitudinal shift, large overlap) and large geographic coverage. PP insensitive germplasm (like CSM63) is more likely to benefit from improved climate forecasts, but PP sensitive cultivars could remain very competitive.

Milestones contributing to Output 9A in 2006

9A.1 Tools for assessing and managing climate variability, Eastern and Southern Africa

KPC Rao

In general, agricultural research treats climate as static by targeting the recommendations to the mean annual rainfall. Though mean annual or seasonal rainfall is a valuable statistic in planning various operations, it does not take into account the dynamic nature of climate. Several researchers have suggested that the more appropriate index for agricultural purposes is the "probability of occurrence" of a given amount of rainfall. The probability information can be derived easily from an analysis of the frequency distribution of annual rainfall but requires long-term observed data. The analysis carried out using historical climate data for 20 locations in Machakos and Makueni districts of Kenya has suggested that minimum of 25 or more years data is required to capture the long-term trends in rainfall fairly well (Figure 9A.4).

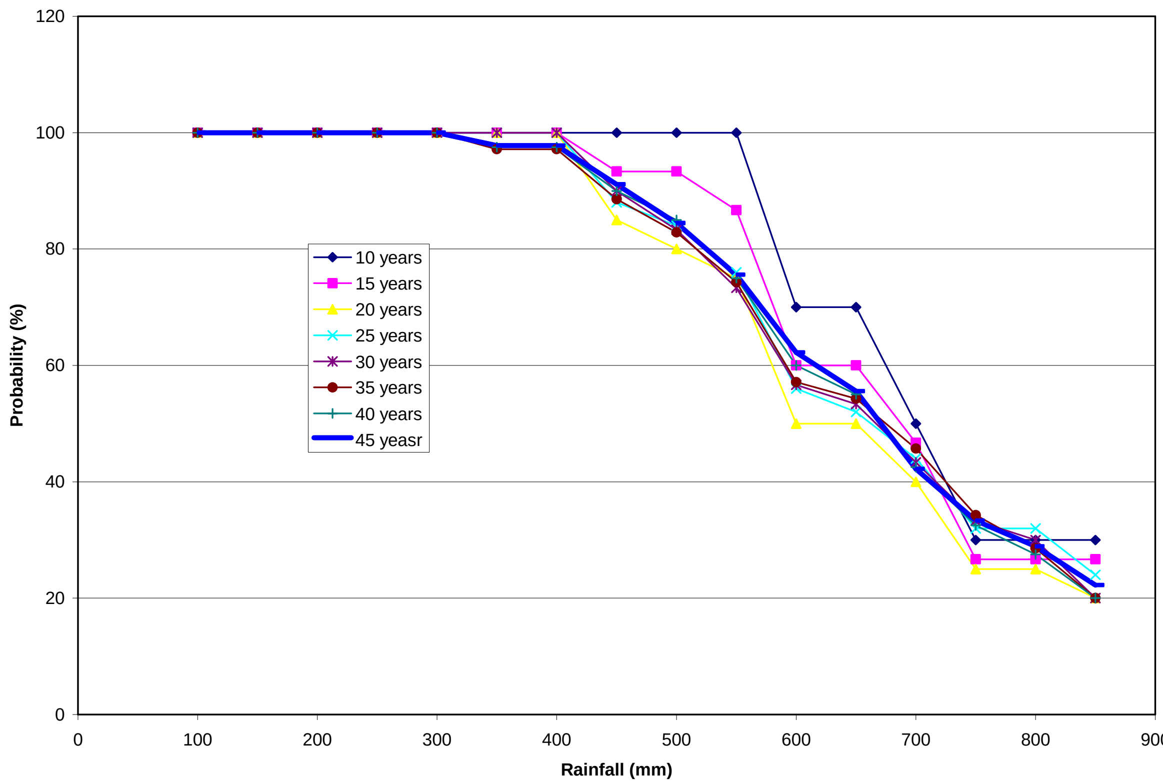


Figure 9A.4: Relationship between probability distribution of annual rainfall and number of years of observed data

Most trials involving development and testing of agricultural technologies are normally conducted over 3 or 5 seasons. In case of rainfed farming the same is not sufficient to capture the effect of high variability associated with the amount and distribution of rainfall and the results can under or over estimate the treatment effects depending on the seasonal conditions that prevailed during the test period. Analysis of the data from a trial conducted at Katumani over 20 crop seasons showed considerable variation in runoff and maize yield. Under such conditions three and five year averages, could lead to relatively large errors in the assessments. For example three season average runoff can be estimated either as 42 mm or 159 mm depending on the period during which the trial was conducted (Table 9A.2). Crop simulation models provide an opportunity to better characterize the effects of variable climate if long-term climatic data is available.

Table 9A.2: Variation in runoff and maize yield due to variability in seasonal rainfall

Period	No of seasons	Seasonal rainfall (mm)	Runoff (mm)		Maize yield (kg/ha) under low input	
			Observed	Simulated	Observed	Simulated
1997 LR to 1998 LR	3	548	159	159	1200	978
1994 SR to 1996 SR	3	230	42	44	550	610
1997 LR to 1999 LR	5	393	99	101	794	672
1994 SR to 1996 SR	5	282	72	62	774	760
1990 LR to 1999 SR	20	329	70	76	963	758
All available	94	299		25		825

Table 9A.3: Deviation in mean annual, short and long rain season rainfall from MARKSIM simulated data.

NO	STATION NAME	Altitude (m)			Years of Observed data	Deviation of observed rainfall from predicted (%)		
		Actual	Derived	Difference		Annual	Short Rains	Long Rains
	KANGUNDO							
1	KITHIMANI D.O'S OFFICE	1280	1280	0	46	-16.8	-23.6	-19.9
2	KATUMANI EXP. RES. STATION.	1600	1828	-228	46	-117.9	-143.7	-114.1
3	MAKINDU MET. STATION	1000	1005	-5	46	4.7	2.5	7.4
4	KIBWEZI, DWA PLANTATION LTD.	914	944	-30	46	12.8	4.0	8.8
5	MACHAKOS,MATILIKU HEALTH CENTRE	1097	1097	0	42	-16.8	-33.2	-10.7
6	MAKUENI UNOA HILL	1204	1158	46	43	12.8	4.0	8.8
7	NTHANGU FOREST STATION	1494	1280	214	43	0.6	11.1	-8.6
8	AIMI MA KILUNGU LTD.	1778	1645	133	42	-3.1	17.6	-20.2
9	MBOONI CHIEF'S OFFICE	1791	1402	389	42	-5.8	-2.0	-15.3
10	MACHAKOS MATUNGULU	1524	1280	244	42	16.2	19.3	5.8
11	B&T MALINDA RANCH, LUKENYA	1524	1584	-60	35	-2.4	-23.4	-14.4
12	KIBOKO TSETSE STATION	975	914	61	46	8.4	-5.3	28.7
13	MWALA LOCATIONAL CENTRE	1250	1280	-30	34	0.6	-17.2	3.7
14	MUTHETHENI CHIEF'S OFFICE	1372	1280	92	31	-46.4	-54.6	-46.0
15	WAMUNYU CHIEF'S OFFICE	1219	1280	-61	31	-17.2	-16.4	-34.1
16	MASII CHIEF'S OFFICE	1341	1280	61	31	-53.5	-46.8	-74.9
17	MACHAKOS F.T.C.	1573	1828	-255	26	-109.2	-138.5	-94.6
18	KATHEKANI RAILWAY STATION	675	761	-86	31	2.5	-8.3	-7.3
19	NATIONAL RANCH RES. STATION KIBOKO	993	1005	-12	21	2.9	-7.6	-16.1
20	IKOYO MWOVE'S FARM	987	914	73	21	0.4	3.0	-2.3

Unfortunately, for most countries good long-term records to capture the high variability associated with the climate systems in the region are not available. Where available, there are also problems with the quality of the available data which include missing values and temporal continuity. Further, crop simulation models used to quantify the impacts of climate variability on crop production require daily data for a range of parameters that often include maximum and minimum temperature and solar radiation and very limited number of the rainfall recording stations collect data on these parameters. Attempts were made to generate the required daily data using a stochastic weather generator MARKSIM and to assess whether or not simulated patterns match the observed pattern for 20 locations in Kenya. In general the predictions were found to be good for many stations (Table 9A.3). However, for Katumani and Machakos FTC stations the predicted rainfall values were found to be much higher than the observed. Preliminary analysis suggested that a part of the error is related to the differences in actual and derived values from the layer. For these two locations the derived altitude values are much higher than the actual values (>200 m). However, good relationship between observed and predicted was observed in case of Nthangu and Mbooni stations where the derived altitudes are less than actual by about the same magnitude. Further analysis with data from Ethiopia and Mozambique to determine under what conditions the weather generators can be applied.

Farmer perceptions and knowledge about climate variability management:
Surveys to assess how small farmers presently negotiate climate variability and how they might change their decisions in the light of additional information were carried out in Kenya, Ethiopia and Madagascar. Analysis of the information collected from Kenya has indicated the following insights:

i. Almost all farmers ranked climate variability as one of the five major constraints limiting crop production in their area. Other constraints include soil type, crop choices/rotations, input costs, and availability of credit
ii. Farmers in general perceived higher risk than the one that is actually indicated by the historical climate data and results of crop simulation analysis. On average farmers rated nearly 53% of the short rain seasons as poor while historical climate data indicated that only 22% of the seasons received less than 200 mm rainfall, the minimum required for harvesting a maize crop without failure.
iii. More than 90% of the farmers considered forecast information as the most useful climate information if it is true in 4 out of 5 years and is available timely in a format that can be used by them with little or no external assistance
iv. Almost all farmers are aware of traditional forecasts and some have confidence in them but most do not use them.
v. Farmers have clear ideas on how to make use of the climate information especially the seasonal climate forecast information, if they have access to necessary resources. They have also identified a range of season specific management options that are of potential benefit and do not require many resources.
vi. Nearly 75% farmers believe that normally their decisions are based on the basis of normal to above normal rainfall expectations. Though farmers are aware of management options that can reduce risk in below normal years and increase production in above normal years, most farmers plan and conduct their farm operations with normal conditions in mind.
vii. Nearly 50% of the farmers are aware of the scientific forecasts made by the Kenya Meteorological department but differed in their confidence in the forecast. Less than 40% of the farmers who are aware of the forecasts indicated that the forecasts are dependable
viii. Among the options for receiving the forecast information, 85% farmers preferred radio. The other popular options are extension agencies and church organizations. Though TV is also identified as an important source its access in rural areas is extremely low.
ix. Most farmers are not comfortable with probabilistic forecasts. They considered information about the amount and distribution of rainfall, and on set and cessation of the rain season as the most important facts.
x. In addition to forecast information, farmers would like to receive additional comments (e.g., about the conditions under which it can go wrong), explanation on agricultural significance, and updates during the season.
xi. Access to credit and improved technologies were considered as major limitations to derive maximum benefit from the forecast information
xii. For farmers to plan and act they would like to receive the information at least one month before the actual start of the season

9A. 2. Modeling crop production in pearl millet-based systems of the Sahel (PhD research)
PBI Akponikpe, C Bielders, UCL; B Gérard, ICRISAT

i. APSIM-millet model calibration and validation in Niger
Tests to calibrate and validate the Agricultural Production Systems sIMulator (APSIM model) for Sahelian conditions for Pearl Millet was done using on-station experimental data (1994-1995) that looked at the interactions of combining cattle manure, millet residues and chemical fertilizer on pearl millet production. The APSIM model was able to simulate grain and biomass production, and plant available water PAW, but failed to simulate other components of the water balance mainly evapotranspiration and drainage (Figure 9A.4). Sensitivity analysis showed that grain yield was sensitive to variation in water balance parameters (cn_bare and swcon) and very sensitive to growth parameters (head_grain_no_max, grain_gth_rate and rue).

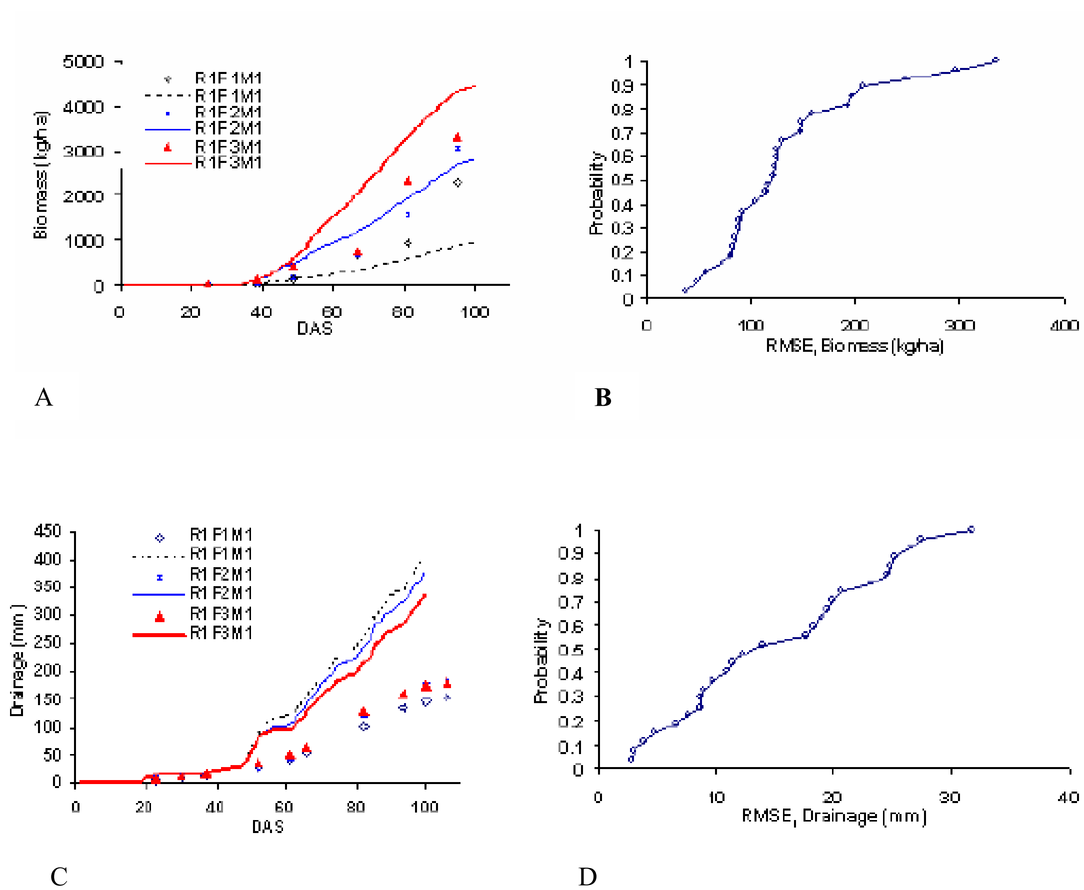


Figure 9A.4 Observed (symbols)and predicted (lines) responses to three selected treatments for A. Change in Pearl Millet biomass over time, B.Model performance RMSE for all treatments (N=27), C. Drainage below roots over time, D. Model performance RMSE for all treatments (N=27)

ii. Effect of photoperiod and sowing date on seven Nigerien millet genotypes
This activity was aimed at providing the basis of eco-physiological parameterization of the APSIM model for optimal nutrient and water conditions for Sahelian millet genotypes. It showed significant behavior differences between genotypes regarding photoperiod (contrast between the landrace Maewa on one hand and landraces Hainikirey, Ankoutes, Zongo + improved genotypes CIVT, ICMV-IS89305, ZATIB on the other). Landraces produced more biomass and less grain yield than improved cultivars. Delayed sowing resulted in decreased biomass

and grain production in almost all the tested genotypes in contrast to the most photosensitive landrace Maewa which production was relatively stable. Eco-physiological parameters were significantly different between genotypes and suggest the need for minimum data collection when using a new cultivar for modeling purposes.

iii. Collecting data from Sahelian farmers' field to validate the APSIM model
Agronomic data for farmer managed pearl millet crops has been collected from farmer fields in the Fakara region since 2004. The data being collected is being used to establish a data base to validate the APSIM model for Sahelian farmer field conditions and develop a decision support tool for cropping interventions. Information is being collected from 3 villages, with 3 farmers selected in each village, taking account of their location in the Fakara (village, type of soil, distance to the village, history of fields, etc.) and fertility management practices. A total of 36 plots have been delineated and geo-referenced within the 9 fields, based on uniform fertility management practices (1 or 2 year old corralling, 1 or 2 years old transported manure, residue or chemical fertilizer application). The soils in each plot have been sampled and physio-chemical characterizations have been undertaken, and the millet crops have been monitored in each season (climate data, soil moisture, plant phenology, and yield). Data collected is now being used to calibrate the APSIM model for further scenario analyses.

9A.3 Assessing rural Nigerien villagers constraints in the access of economic assets and development actions, through an agent-based modeling methodology *Mehdi Saqalli*

i. Assessing the impacts of family organization in Sahelian rural multi-activity systems using an agent-based model,

The complexity of family organization and the diversity of income sources is often neglected while analyzing development issues in Africa. The purpose of this research is to analyze the impacts of this complexity on income and sustainability in the case of rainfed farming systems in villages of south west Niger, where rains are low and irregular, soils are poor and social relationships are vital. An individual-centered agent-based model (ABM) combining different scientific disciplines is used to evaluate the consequences of two types of family structures as identified during field investigations: a unitary family structure (UFS), where families remain enlarged, under the rule of a patriarch, and a non cooperative family structure (NCFS), where families are mononuclear and not decision-centered. Multiple sources of income (millet farming, migration and gardening) are explicitly taken into account. Long-term simulation results show that family organization has strong effects on income levels and distribution amongst villagers, but also on demographic growth: no support from parents in the NCFS forces young unmarried males to postpone their wedding. Even if millet farming still remains the main source of income, gardening and migration are necessary to bridge the gap until the next harvest. In the NCFS, resilience is greater partly because a greater proportion of income is derived from activities other than farming. Results suggest that the UFS, which is the most dominant in southern Soudanian environments, is a more productive "version" of the system but also a more fragile one in Sahelian conditions. The NCFS fits better with recent demographic growth and cropland growth data whereas the UFS fits better to 1950 to 1980 data. One can then suggest a historic shift for that particular society from a dominant unitary mode to a non cooperative one, as it occurred for more densely populated sites in southern Niger.

ii. A low-cost indigenous perception-based regional mapping methodology for rural support in Niger: analysis of an experience
The relevance of the use of indigenous perception-based maps on a regional level, in the context of rural community economic development in Niger as a sample test of the method for West Africa was examined. Expensive and expert-based data collection methods *de facto* restrict access to relevant information to development agencies. Between the village-level Participatory Research Assessment method and statistical non-locally based methods such as satellite image analyses, there is a need for an indigenous perception-based regional mapping methodology. Advantages include its low cost, its action-oriented easily understandable method and its regional-level and more dynamic perspective. Two regions of Niger are examined, and a comparison of the local ecological and economic driving forces, the ease of understanding the results and the relative cost of the methodology permits an assessment of whether such a tool can be useful to development agencies for rural development planning.

9A.4 Simulating Cereal Legume Rotations in southern Africa

Bongani Ncube, John P Dimes, Mark T van Wijk, Steve J Twomlow; Ken E Giller – ICRISAT and Wageningnen Agricultural University

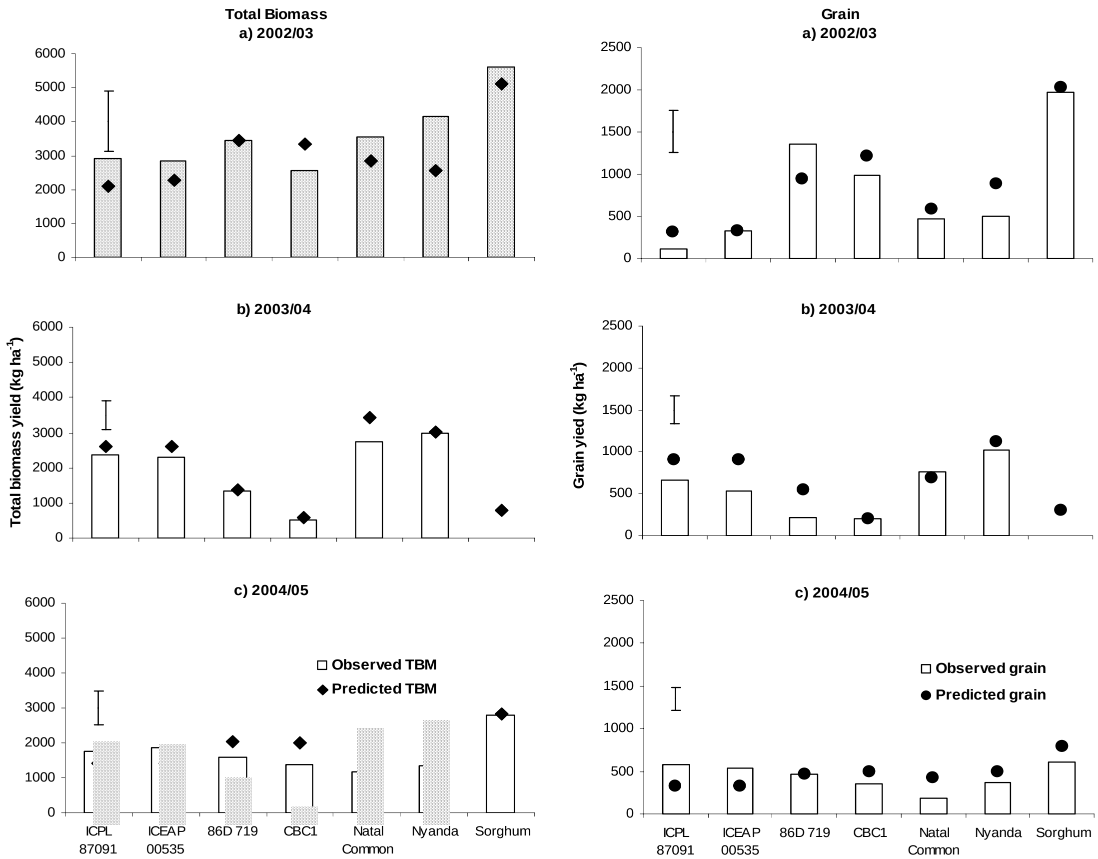


Figure 9A.5. Observed and predicted total biomass and grain yield of legumes across three cropping seasons at Lucydale. Error bars represent standard errors of the means of the yields. Sorghum failed to establish in 2003/2004.

We assessed how accurately the APSIM model can predict observed legume and rotation sorghum yield and how the model can assist in explaining the mechanism of the residual benefit of legumes to sorghum under dry semi-arid conditions. The model was used to simulate the measured soil and plant responses in a legume-sorghum rotation experiment conducted at Lucydale, Matopos Research Station in south-western Zimbabwe, between 2002 and 2005 Local climate, measured soil mineral N, soil organic matter (SOC) and water data were used as inputs to the model. Sequences of cowpea (*Vigna unguiculata* (L.) Walp), pigeonpea (*Cajanus cajan* (L.) Millsp.), groundnut (*Arachis hypogaea* L.) and sorghum (*Sorghum bicolor* (L.) Moench) were used to simulate the rotations. Existing parameters in the model for cowpea, pigeonpea and sorghum were found to capture the observed phenology and grain partitioning of the experimental cultivars reasonably well. In the case of groundnut, new cultivar parameters were constructed and calibrated using the observed harvest index and flowering data. APSIM predicted total biomass and grain yields of the legume phase well. Sorghum yield was also predicted well in rotation after cowpea and groundnut, but the model under-predicted sorghum yield after pigeonpea and after sorghum in 2004/05 (Figure 9A.5). The under-predictions were probably due to the exclusion of leaf fall in pigeonpea, and an under-estimation of soil N mineralization in the case of sorghum. Model output on sorghum N and water stresses indicated that the legume-cereal rotation is more driven by soil nitrogen availability than water availability even under semi-arid

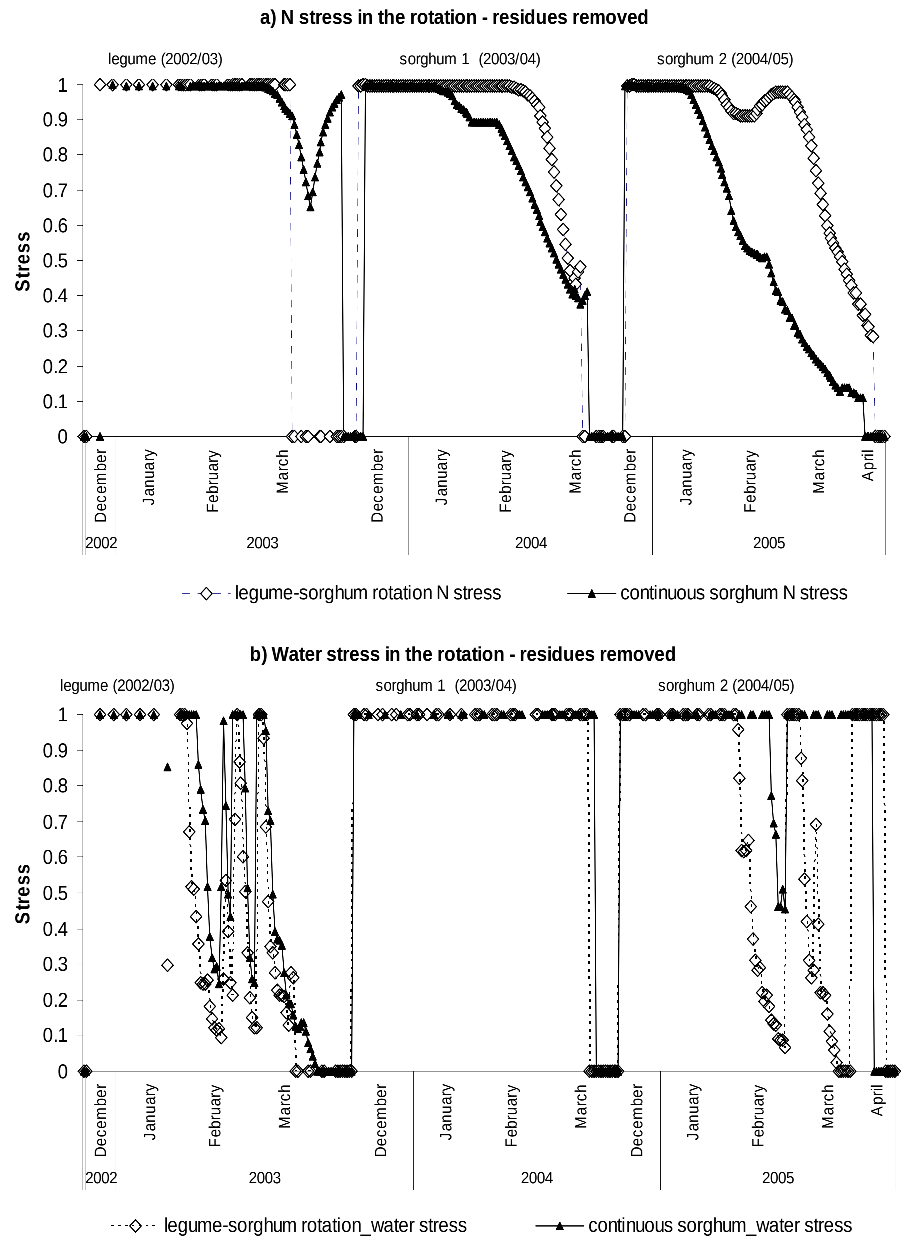


Figure 9A.6 Nitrogen and water stress predictions in the legume sorghum rotation with residues removed, over three cropping seasons at Lucydale. The open symbols represent plots planted with legumes in 2002/03, while the black symbols represent plots planted

conditions (Figure 9A.6. Further testing of the model will assist in the understanding of other processes in the legume-cereal rotations in dry environments.

9A.5 Agroclimatic characterization of APRLP-ICRISAT nucleus watersheds in Nalgonda, Mahaubnagar and Kurnool districts. India. *Kesava Rao AVR, Wani SP, Piara, Irshad Ahmed M and Srinivas K.*

Knowledge on the agroclimatology of a region is a valuable tool in crop planning. Agroclimatic analysis of the Andhra Pradesh Rural Livelihoods Projects nucleus watersheds in three target districts (Nalgonda, Mahabubnagar and Kurnool) has been carried out on the basis of agromet data for the period 1971-2003. During the southwest monsoon season, more than 1000 mm rainfall was received at Nemmikal and Appayapally, while it was as low as 143 mm at Nandavaram. More than 85% of the annual rainy days occur during the five-month period – June to October.

Though all the locations have a semi-arid type of climate, there is a tendency for the climate to temporarily shift towards the drier side. About 45% of the study period now shows an arid type of climate. Among the watersheds, Malleboinpally has the most stable climate with 85% of the total years in its normal semi-arid climate. At Nemmikal, there appears to be a slight trend towards dryness in the past 25 years, after 1978, as the climate was never the dry sub-humid type, and it slowly has been tending towards the arid type. Analysis of water balances in extreme rainfall years indicated that many locations recorded water surplus even in dry years. Between the wet and dry years, variation in the water surplus is much higher compared to the water deficit. Nemmikal (medium-deep Vertisol) and Nandavaram (deep Vertisol) watershed provide greater opportunity for double cropping. Appayapally, Thirumalapuram and parts of Nemmikal watersheds with medium-deep Alfisols, provide opportunity for double cropping with relatively short duration crops, but are more suitable for intercropping with medium-duration crops such as pigeonpea and castor. Watersheds in Kacharam, Mentapally, Sripuram, Malleboinpally and Karivemula have medium-deep Alfisols and provide greater potential for sole cropping during rainy season with crops of 120-130 days duration, and intercropping with short to medium-duration crops to make better use of soil water availability. Early season drought occurs at Karivemula and Thirumalapuram and early and mid-season droughts occur at Nandavaram. These sites would require crop/varieties tolerant to early or mid-season droughts depending upon the location. It is also observed that Mentapally, Malleboinpally, Nemmikal and Appayapally have greater potential for water harvesting.

Assured rainfed crop-growing season is about 165 to 175 days for the Vertisols areas and about 130 to 150 days for the Alfisols areas. There is variation in both the beginning and ending of the season: however, the end is more variable compared to the start. No definite relationship exists between the beginning and length of the growing season.

<u>Priority 4C, Specific goal 1: Improved management practices that enhance the productivity of water</u>
<u>Priority 4D, Specific goal 1: Improve understanding of degradation thresholds and irreversibility, and the conditions necessary for success in low productivity areas</u>
<u>Priority 4D, Specific goal 3: Identify domains of potential adoption and improvement of technologies for improving soil productivity, preventing degradation and for rehabilitating degraded lands</u>
<u>Priority 4D, Specific goal 5: Improve soil quality to sustain increases in productivity, stability and environmental services through greater understanding of processes that govern soil quality and trends in soil quality in intensive systems</u>
<u>Priority 4D, Specific goal 6: Design methods to manage and enhance biodiversity to increase income, reduce risk and vulnerability through IPM, crop diversification and rotations, and genetic diversity within crop species</u>

Output 9B. Affordable and sustainable crop management options (nutrients, water management, crop-livestock, IPM, cultivar, rotations) developed and promoted in collaboration with NARES partners in Africa and Asia

Output target 2007: 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

ICRISAT staff in sub-Saharan Africa have 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 Eastern, Southern and West Africa – micro-dosing. This starts from the proposition that farmers are risk averse, but will take larger risks as they learn about new technologies. It starts from the proposition that resource constraints prevent most farmers from pursuing rates of fertilizer application recommended by most national extension agencies. Rather than asking how can a farmer maximize her yields or profits, micro-dosing asks how can a farmer maximize the returns to a small initial investment – that might grow over time, turning deficits into surpluses. How, for example, might a farmer maximize her returns to investing two chickens in a bit of fertilizer? Next year it may be four chickens and the following year a goat.

Our results have consistently shown that fertilizer micro-dosing can be successfully used in both low and high potential areas where farmers cannot afford to purchase the current recommended rates of fertilizer. This innovative technology involves the precision application of small quantities of fertilizer (macro-nutrients in sub-Saharan Africa) close to the crop plant. This enhances fertilizer use efficiency 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 (Figure 9B1).

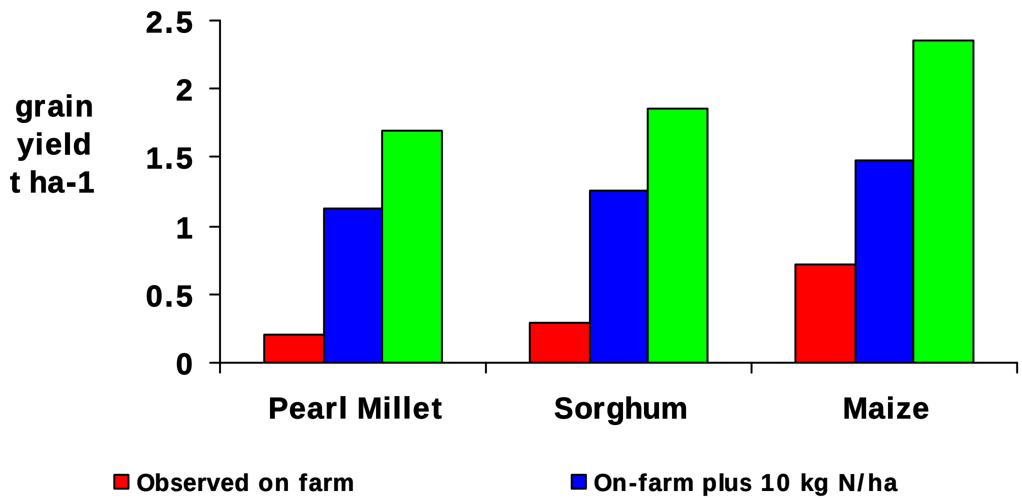


Figure 9B1. Observed yield gap in southern Zimbabwe, Matobo, 2004 (moderate drought year)

In the last 12 months ICRISAT staff have undertaken a wide range of research and development initiatives on their own, or in collaboration with a whole host of traditional and none traditional collaborators to promote the micro-dosing concept throughout sub-Saharan Africa (see Box 9B1). Donor support from ACIAR, DFID, DGDIC, IDRC and the African Development Bank continue to help us develop and promote this initiative with an ever increasing range of partners and encourage fertilizer companies to experiment with more imaginative marketing strategies (see Box 9B2 and Centre Project 1 for more detail[REF11]s), while encouraging farmers to experiment with application strategies suited to their investment priorities, and risk preferences.

Box 9B1 Microdosing, Africa Wide

Niger. Hill-placed application of fertilizer: DAP, urea and various manure combinations. 3-year on-farm trial in a drought-prone area with poor sandy soils, 2003 onwards, to validate previous on-station results. Micro-dose of DAP at planting increased millet grain yield by a factor of two to six, depending on variety and initial soil nutrient status.

Burkina, Faso, Niger, Mali. Hill-placed application of fertilizer, 2-year on-farm trial in 3 countries. Sorghum and millet grain yields increased by 44 to 120%, farmers' incomes increased by 52 to 134%. Technology currently used by nearly 13,000 farmers through a wide range of strategic partnerships with NGOs and the FAO "Warrantage Program' which improves household access to fertilizer inputs.

Based on the encouraging results from the 2-year USAID TARGET project on fertilizer micro-dosing and the warrantage system, CORAF/AfDB has funded a 3-year project entitled " Fertilizer micro-dosing and drought tolerant varieties technology transfer for small farmer properity in the Sahel". This project which started in 2005 is being implemented in Burkina Faso, Niger and Senegal. Farmers Field Schools are being used to demonstrate the potential of the technology and to enhance it dissemination amongs end users. Results in 2005 and 2006 showed that grain yields of sorghum and millet have doubled under the fertilizer micro-dosing technology as compared to the farmer's practice.

Ghana. Multilocation on-farm trials on maize, sorghum and millet. Microdosing increased grain yield by 40 to 300% on different crops, compared to farmer practice. Microdosing also increased nitrogen-use efficiency by 50 to 90% compared to recommended fertilizer rates.

Zimbabwe. 3 seasons of on-farm validation trials to support more than 3,000 multi-location farmer managed trials on maize, sorghum and millet. 25 to 50 kg per ha of ammonium nitrate as a top dressing increased cereal grain yields by 25 to 40% across all households irrespective of season. Micro-dosing is an initial step towards household food security. Further yield improvements achieved when microdosing is combined with manure and conservation agriculture. Technologies currently being promoted to more than 150,000 households through strategic partnerships with NGOs and NARS. Pilot testing of small packs of fertilizer with private sector to improve access is underway.

Republic of South Africa 3 seasons of on-farm validation trials supported by an input supply scheme by the private sector to increase access to fertilizer. Grain yield increases of more than 50% have been observed, with more than 1000 households purchasing fertilizer in 2005-2006.

Kenya Dissemination materials developed in Zimbabwe adapted by the Catholic Relief Service for their relief and development programs.

Milestones contributing to Output 9B in 2006

I. Improved fertilizer recommendations and policy for dry reasons of southern Africa. ***John Dimes***

The objective of this ACIAR funded project, "Improved fertilizer recommendations and policy for dry regions of southern Africa", is to increase use of inorganic fertiliser by smallholder farmers 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 in Limpopo Province of South Africa with a wide range of partners, including Progress Milling, a large private-sector grain milling and trading firm; Sasol Nitro, a fertilizer manufacturer; the Limpopo Province Department of Agriculture, and LIMPAST, a farmer development organization which has support from ARC, the national agricultural research organization. The project was initiated in July 2003 and an Extension phase is due for completion in September 2007.

Box 9B2 Project initiatives that are continuing to contribute to output target 9B.

- CORAF/AfDB Funded project entitled " Combining Water Harvesting Techniques and Nutrient Management to Sustain Food production in the Dry lands of West Africa Implemented in Burkina Faso, Mali, Niger and Senegal; Partners are : ICRISAT, TSBF-CIAT, CERAAS/ISRA (Centre d' Etude Regional pour l' Amelioration de l' Adaptation a la Secheresse), Senegal; Institut de l' Environnement et de Recherches Agricoles (INERA), Burkina Faso; Institut National de Recherches Agronomiques du Niger (INRAN), Niger; Institut d' Economie Rurale (IER), Mali; Groupement Nabonswende de Tougouri, Burkina Faso; Entente des groupements Associes de Toubacouta (EGAT), Senegal; Caritas-Kaolack, Senegal; Projet Intrants FAO, Niger and EUCORD (Former Winrock International), Mali.
- CORAF/AfDB funded project entitled " Promoting use of indigenous Phosphate Rock for soil fertility "recapitalization" in the Sahel" ICRISAT, TSBF-CIAT, CERAAS/ISRA (Centre d' Etude Regional pour l' Amelioration de l' Adaptation a la Secheresse), Senegal; Institut de l' Environnement et de Recherches Agricoles (INERA), Burkina Faso; Institut National de Recherches Agronomiques du Niger (INRAN), Niger Groupement Nabonswende de Tougouri, Burkina Faso; Entente des groupements Associes de Nganda (EGAN)), Senegal; Union des Comites Ruraux Villageois de la Zone de Latmingue (UNICOM), Senegal; and Projet Intrants FAO, Niger
- McKnight Foundation project entitled : ALIVE and nutritious cropping systems : A legume intensification and variety enhancement participatory apprach". Implemented in Mali; partners are : ICRISAT, Institut d' Economie Rurale (IER), Hellen Keller International (HKI), Michigan State University (MSU); Union Locales des producteurs des cereals (ULPC) and Association des Organisations Professionnelles Paysannes (AOPP).
- CPWF (Challenge Program on Water and Food) funded project on « Enhancing rainwater and nutrient use efficiency for improved crop productivity, farm income and rural livelihoods in the Volta Basin" Implemeted in Burkina Faso and Ghana; Partners are : ICRISAT; TSBF-CIAT; Kenya; Centro International de Agricultura Tropica (CIAT), Colombia); Savanna Agricultural Research Institute (SARI), Ghana; Institut de l' Environnement et de Recherches Agricoles (INERA), Burkina Faso; The Semi-Arid Food Grain Research and Development (SAFGRAD), Burkina Faso; The United Nations-Institute for Natural Resources in Africa (UNU-INRA), Ghana; The Center for Development Research (ZEF), Germany.
- DFID Protracted Relief Program Project 'Achieving sustained improvements in the crop production of poorer, smallholder households of dryland cropping systems in southern Zimbabwe'. Partners are FAO, CARE, World Vision, CAFOD, CRS, OXFAM GB, Save the Children UK, Zimbabwe Fertilizer Company, AREX
- ACIAR Project 'Improved fertiliser recommendations and policy for dry regions of southern Africa'. Partners include SASOL, Limpopo Provincial Dept of Agric, Progress Mills, LIMPAST, ARC
- IDRC Project 'Increasing the Impacts of Soil Fertility Research in Southern Africa' SOFECSA, NASFAM, LIMPAST, SASOL, Zimbabwe Fertilizer Company, Zimbabwe Opportunities Investment Center

Following 3 seasons of on-farm trials, results show that low doses of top-dress Nitrogen fertilizer can increase grain yield by more than 50% compared to current farmer practice and close to yields of current recommended rates in drier seasons (Figure 9B2).

Analysis of the value cost ratio for low and recommended doses (Figure 9B2) show that the low dose rates provide much higher returns on investment in wet (2006) and dry seasons (2004, 2005), confirming that this technology is a more risk acceptable fertilizer option for drier regions.

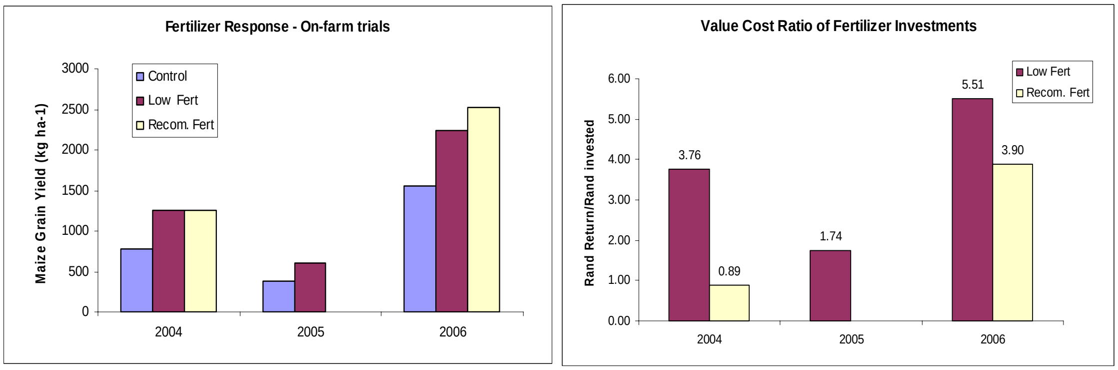


Figure 9B2. Grain yield response and value cost ratio of fertilizer investments for on-farm maize trials conducted across 3 growing seasons in Limpopo Province, RSA.

In 2005/06, Sasol Nitro, Progress Milling and ICRISAT embarked on a pilot study to test the sale of small packs of fertilizer to smallholder farmers. This involved investment by Sasol Nitro in registering and packaging starter and top-dress fertilizer in 10 and 20 kg packs, and Progress Milling investing in the distribution of fertilizer to about 20 of their depots operating in rural villages throughout Limpopo Province. Results show that about 1500 small packs of fertilizer were sold to households. In villages where fertilizer was commonly used (Figure 9B3, Perskebult), daily records of sales show that purchase of 50kg bags were preferred, although about 20% of sales were nevertheless in small packs. In 2 villages (Motupa and Lenyene) where fertilizer was not commonly used (Figure 9B3), almost 100% of sales were as small packs. These results are supportive of the hypothesis that small packs encourage farmer experimentation in fertilizer use. At the same time, a collaborating seed company, Pannar, reported that distribution of small seed packs in the community based outlets increased sales of improved seed by about 25 tonnes in 2005-06.

ii. Dissemination

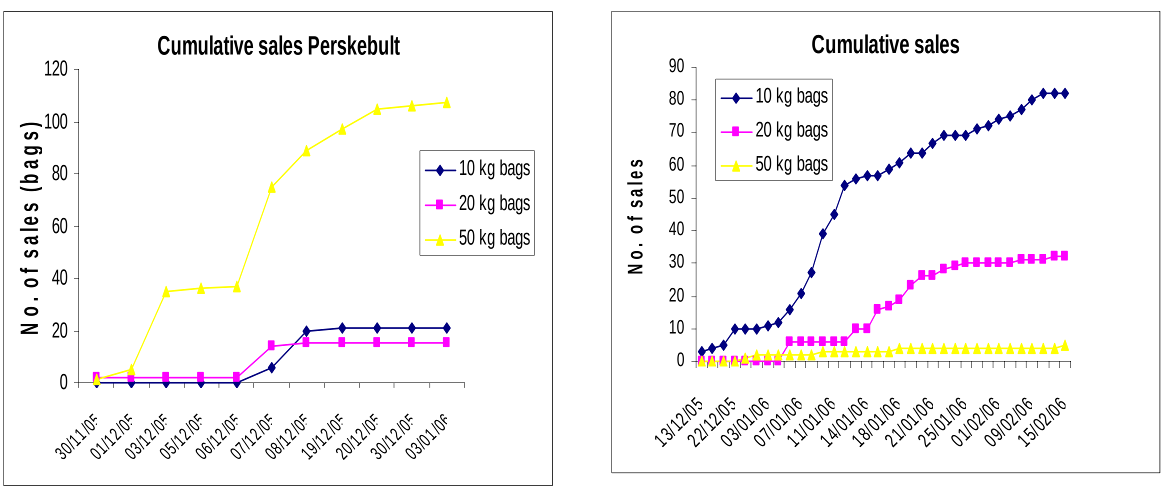


Figure 9B3. Daily sale of fertilizer pack sizes at Progress Milling depots at Perskebult, and Motupa+Lenyene during a dry season in Limpopo Province.

- Participation in the Africa Fertilizer Summit, and a plenary presentation Dr William Dar 'Developing Fertilizer Interventions for Semi-Arid Areas' – Abuja, Nigeria, June 2006
- Flyer 'A Pathway to Africa's Green Revolution: ICRISAT's perspective on fertilizer interventions for semi-arid areas' distributed at the Africa Fertilizer Summit and the 'NEPAD Food Security Summit', Abuja, Nigeria, December, 2006.

- Fatondji D. Martius C., Bielders C.L., Vlek P.L.G., Bationo A., Gerard B. 2006. Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. Nutrient Cycling in Agroecosystems Journal DOI: 10.1007/s10705-005-6209-9
- Ncube, B., Dimes, J.P., Twomlow, S., Mupangwa, W., Giller, K.E., 2006. Raising the productivity of smallholder farms under semi-arid conditions by use of small doses of manure and nitrogen: A case of participatory research Nutr Cycl Agroecosyst. DOI: 10.1007/s10705-006-9045-7
- Twomlow, S., and Rao, K.P.C., 2006. Research on integrated soil and water management in semi-arid eastern and southern Africa: Past Experiences, current activities and future thrusts. In: Shiferaw, B. and Rao, K.P.C. (Editors). Integrated management of watersheds for agricultural diversification and sustainable livelihoods in eastern and central Africa: Lessons and experiences from semi-arid South Asia. Proceedings of the International Workshop held at ICRISAT, Nairobi, 6-7 December, 2004. Patancheru 502324, Andrha Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. 53-58. ISBN 92-9066-487-8. Order Code CPE158
- Gerard B. 2006. Intensification of Sahelian rainfed agroecosystems: development of site specific management decision support tools to allocate local resources and recommend use of mineral fertilizers under risky environments. In Climate Information for Development Needs: An Action Plan for Africa. GCOS Conference, 18-21 April 2006. Addis-Ababa. Ethiopia
- Twomlow, S., Rohrbach, D., Rusike, J., Mupangwa, W., Dimes, J., Ncube, B., 2006. Spreading The Word On Fertilizer In Zimbabwe. SADC Land and Water Management Program Scientific Conference – Malawi, Feb 2006

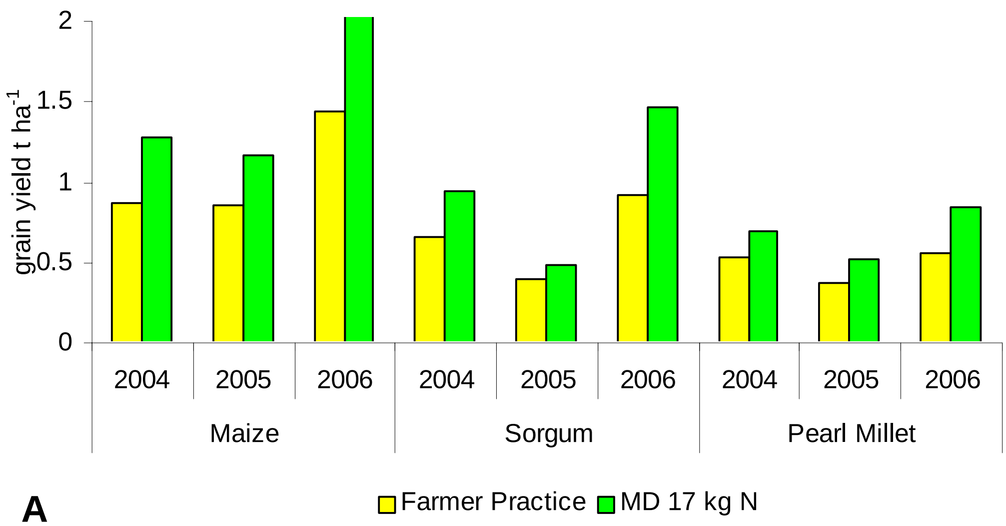
iii. Policy Briefs – ICRISAT Zimbabwe

- Twomlow, S., and Rohrbach, D. 2006. Achieving Sustained Gains in the Food Security of Vulnerable Households. ICRISAT-Bulawayo Briefing Note 1, September 2006.
- Mazvimavi, K., Rohrbach, D., Twomlow, S. and Hove, L., 2006. Building sustainable fertilizer delivery systems for drought prone regions. ICRISAT-Bulawayo Briefing Note 2, September 2006.
- Mazvimavi, K. and Rohrbach, D., 2006. Do seed fairs improve food security and strengthen rural markets? ICRISAT-Bulawayo Briefing Note 3, September 2006.
- Twomlow, S., and Hove, L., 2006. Is conservation agriculture a viable option for vulnerable households? - ICRISAT-Bulawayo Briefing Note 4, September 2006.
- Mazvimavi, K. and Rohrbach, D., 2006. Quantifying vulnerability – accurately reaching those who are most in need. ICRISAT-Bulawayo Briefing Note 5, September 2006.
- Hove, L., 2006. Agricultural technology transfer under relief and recovery programs in Zimbabwe: Are NGOs meeting the challenge? ICRISAT-Bulawayo Briefing Note 6, September 2006.

9B. 1 Science in Agricultural Relief and Development Programs: Case Studies from Zimbabwe

Drought is endemic in southern Africa. Farmers in much of Zimbabwe, for example, experience drought once every two to three years. Households have traditionally coped by reducing their food intake, selling animals and looking for off-farm employment. But the current high rates of inflation and unemployment have now constrained these options. Relief agencies have traditionally responded to drought by providing farmers with enough seed and fertilizer to enable them to re-establish their cropping enterprises. But, in the absence of these interventions there are limited sustainable options for farmers to maintain higher productivity levels.

ICRISAT has been working with government, NGOs and the donor community to test more sustainable farming strategies that will increase food production levels even under drought conditions. For years, we sought to develop more drought tolerant varieties of sorghum, pearl millet and groundnut. But these offered only limited gains in productivity. More recently, ICRISAT and its partners have been testing strategies to sustainable improve crop productivity. These encompass two major components – the precision application of small doses of nitrogen-based fertilizer and the application of planting basins, which concentrate limited water and nutrient resources to the plant. These simple technologies have increased the average yields being obtained by more than 200,000 farm households by at least 30% since 2004 (Figure 9B4). Rather than simply handing free inputs to farmers, this strategy teaches farmers how to apply the inputs most efficiently. The pursuit of input use efficiency provides higher and more sustainable productivity gains necessary to achieve food security in drought prone farming systems, and provide incentives for the private sector to develop input supply channels.



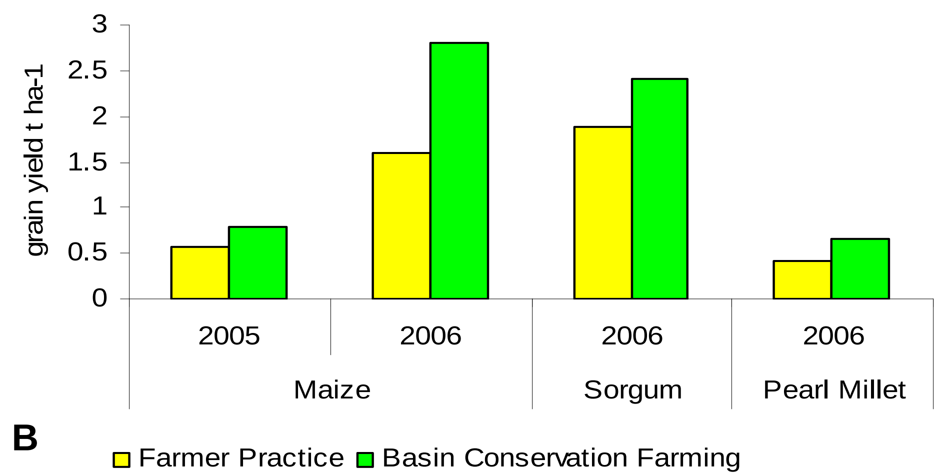


Figure9B4 Average yield increases obtained in southern Zimbabwe since 2004 to A. Microdosing and B. Basin Conservation Farming

i. Planting Basins increase maize yields for smallholder farmers in the semi-rid areas of southern and western Zimbabwe *L Hove, S J Twomlow, D Rohrbach, Nester Mashingaidze, M Moyo, Putso Maphosa, W Mupangwa*
Working with Non Governmental Organization (NGO) partners, ICRISAT has been promoting a conservation agriculture package that has

potential for use by smallholder farmers in semi-arid areas. Central to the package are the planting basins which measure approximately 15 cm long, 15 cm deep and 15cm wide. These basins are prepared during the dry season when demands on family labour are relatively low. They are dug without having to plough the field, thus overcoming the animal draught power shortages. Basin planting works on the principle that rather than spreading nutrients and water uniformly over the field, it concentrates these in the basins to maximize yield for a given level of inputs. When the rains begin, the basins collect rainwater and ensure good germination and a healthy crop stand, even if the rains are erratic. The basin is combined with other crop/soil management practices, such as the spreading of crop residues over the field to protect the top soil against erosion, or with manure and/or fertilizer. The basin technology was evaluated under smallholder farmer management for two cropping seasons from 2004 to 2006 in dry areas of southern and western Zimbabwe. Compared to ploughing, basins significantly increased maize grain yield across eight districts in the first season (Figure 9B4). In the second season, data from 435 farmers across 10 districts showed that basins gave higher maize grain yield and water use efficiency compared to ploughing. Yield increases for districts ranged from 15 to 72% with a mean of 36%. The basins yield advantage was maintained regardless of the soil fertility amendment used (Table 9B1). The basin technology has potential for adoption by smallholders despite the challenges farmers face with respect to labour for basin preparation and weed control, as well as achieving soil cover using crop residues.

Table 9B1. Maize grain yield (kg ha^{-1}) and water use efficiency (kg ha^{-1}/mm total rainfall) response to planting basins and ploughing for 10 districts of southern and western Zimbabwe as influenced by soil fertility amendment used, 2005/06 season

Fertility amendments used	Tillage	n	Grain yield	Water use efficiency
Basal inorganic + Top dressing	Basins	108	2676^{a}	3.97^{a}
	Plough	56	2118^{b}	3.11^{b}
Manure + basal inorganic + top dressing	Basins	140	2485^{a}	3.56^{a}
	Plough	19	1678^{b}	2.47^{b}
Manure + top dressing	Basins	125	2408^{a}	3.63^{a}
	Plough	105	1705^{b}	2.72^{b}
Top dressing only	Basins	16	2165	3.31
	Plough	84	1780	2.63
Sed	Fertility amendments used		268.6***	0.424***
	Tillage		278.3***	0.439***
	Fertility amendment used *tillage		275.3ns	0.434ns

Within each fertility management category, tillage means with different superscripts differ ($p<0.05$)

ii. Put your plants on a nitrogen pill – an alternative microdosing strategy: Preliminary results from Zimbabwe. *N. Mashingaidze, P. Belder, S.J. Twomlow and L. Hove,*

Due to unreliable rainfall, farmers in semi-arid areas of southern Africa are better off applying lower rates of inorganic fertilizer on more fields - rather than concentrating a limited supply on one field that might succumb to a mid-season drought. Over the last three years, precision application of ammonium nitrate (AN), known as microdosing, has been extensively tested in Zimbabwe. The current practice is based around a level crown bottle cap of AN applied to three cereal plants at the 5 - 6- leaf stage. Although the results have shown consistent yield increases in excess of 30% (see earlier figure), 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 the conventional prills. Farmer-based trials in southern Zimbabwe were carried out under conventional tillage and hand-based conservation agriculture practices. Microdosing led to a significant increase ($P<0.01$) in both maize grain yield and water use efficiency (WUE). Although there was no statistical difference in yield from tablet or prill formulation, there was a trend of increased maize grain yield associated with the tablets under both tillage systems (Table 9B2). This translated into significant increase (P=0.01) in agronomic nitrogen use efficiency (ANUE) of up to 80% under the basin system. This increase in ANUE is attributed to the lower solubility of tablets, which may have resulted in a reduction in leaching losses from the root zone. A further seasons trials are planned to confirm that the tablets are a viable alternative to microdosing with a crown bottle cap, and further laboratory work will be undertaken to look at leaching characteristics.

Table 9B2: The effect of applying small doses of prill and tablet AN formulations on grain yield (kg ha^{-1}); WUE (kg of grain ha^{-1}/ mm^{-1} of rain) and ANUE (kg of grain ha^{-1} / kg of N applied ha^{-1}) in the flat and basin tillage systems in Masvingo in 2005/06 cropping season

AN treatment	*Flat*			*Basin*		
	Yield	WUE	ANUE	Yield	WUE	ANUE
Control	1943 ^{b}	2.31 ^{b}		2474 ^{b}	2.93 ^{b}	
Prill	3190^{a}	3.83^{a}	39.7	3593^{a}	4.30^{a}	36.2 ^{b}
Tablet	3313^{a}	3.97^{a}	44.2	4257^{a}	5.12^{a}	65.8^{a}
SED	453.5	0.531	14.51	554.9	0.642	10.85
P value	0.006	0.004	NS	0.008	0.005	0.01

Column means followed by different letters differ at P <0.05

9B.2 Integrated Genetic and Natural Resource Management interventions to enhance rural livelihoods within the watersheds of Asia[REF12]

i. Enhanced Productivity and Incomes through Balanced Crop Nutrition in Madhya Pradesh and Rajasthan Watersheds *Ch Srinivasarao, SP Wani, KL Sahrawat and G Pardhasaradhi*

Effect of balanced crop nutrition for a range of on-farm trials was studied at three watersheds in Madhya Pradesh and one in Rajasthan. Soil test data suggests multiple nutrient deficiencies in these soils particularly sulphur, zinc and boron (Table 9B3).

Table 9B3 Average nutrients status of soils for three watershed in Madhya Pradesh and one in Rajasthan

Parameter	Madhya Pradesh			Rajasthan
	Vidisha(n=31)	Dewas (n=24)	Guna(n=18)	Bundi (n=36)
Organic carbon(%)	0.46-0.92(10)**	0.30-1.00(17)	0.51-1.11(0)	0.18-1.17(39)
Available P(mg kg^{-1})	0.50-14.1(90)	0.20-10.8(96)	0.10-8.40(72)	0.90-20.1(53)
Available K (mg kg^{-1})	97-285(0)	46-456(4)	86-179(0)	23-563(18)
Available S (mg kg^{-1})	2.9-9.8(100)	3.9-9.5(100)	2.7-14.3(89)	3.3-50.9(72)
Available Zn (mg kg^{-1})	0.10-0.42(100)	0.12-0.56(100)	0.24-1.74(78)	0.20-1.80(67)
Available B (mg kg^{-1})	0.12-0.34(100)	0.20-0.80(96)	0.60-2.20(0)	0.10-0.98(72)

*(n=) No of farmer's fields sample; ** ()Percentage deficient*

Based on these results nutrient management options were decided for each crop. Initial results summarized in Table 9B. suggest that based on soil test analysis, application of nutrients improved the productivity and income levels in these dryland regions.[REF13]

ii. Contribution of improved varieties and management to yield enhancement in Sujala Watersheds in Karnataka, India. *Piara Singh, V Nageswara Rao, BK Rajshekhar Rao, Mukund Gorakshkar, K Krishnappa, and SP Wani,* [REF14]

Kolar, Tumkur, Chitradurga, Haveri and Dharwad districts of Karnataka are drought prone with low and erratic rainfall that ranges between 570 to 750 mm annually. Crop productivity is consequently low and unstable, resulting in poverty amongst the rural population. These districts are the focus of the Government of Karnataka's Sujala watershed project that aims to improve the livelihoods of the rural people through the improved management of natural resources and enhancing cropping system productivity, with technical assistance provided by ICRISAT. The purpose of the project is to enhance productivity and crop diversification in these districts, increase farmer's income and minimize economic risks.

The first step in the collaboration was to collect soil samples (410 in total) from ten nucleus watersheds. Subsequent analysis of soil samples indicated that more than 50% of farmers' fields were deficient in available sulfur, zinc and boron, in addition to low phosphorus and low organic carbon, thus reducing the potential of the production systems. In the 2005 crop season, farmers in each watershed selected ICRISAT, UAS and proprietary hybrids/improved cultivars of major crops and embarked on a participatory evaluation using both traditional and improved management (improved agronomy, balanced nutrition and IPM) practices. Crops evaluated were finger millet (*ragi*) and groundnut in Kolar and Tumkur districts, sunflower in Chitradurga, maize in Haveri, sorghum in Dharwad, and soybean in Chitradurga, Haveri and Dharwad districts and pigeonpea in all the five districts.

Each farmer demonstration was laid out on one-acre of land. Approximately one half acre was allocated to local varieties grown under the farmers traditional management practices (T1). In another half acre improved cultivar was sown, which, was further divided into two parts, one having traditional management practices (T2) and the other having improved management (T3). The best-bet treatment (T3) included application of 70 kg Di-ammonium Phosphate, 100 kg urea, 5 kg borax, 50 kg zinc sulphate and 200 kg gypsum per ha^{-1} for cereals. For legumes urea application was reduced from 100 kg to 40 kg ha^{-1} and the other nutrient applications remained the same.

***Evaluation of* ragi *(finger millet) in Kolar and Tumkur districts*:** Thirty-six farmers in Kolar district and eight farmers in Tumkur district evaluated improved cultivars of *ragi*. The varieties and their yield responses to the three management practices are summarized in Table 9B. Due to good rainfall the *ragi* yields were generally good, with inherent soil fertility responsible for yield differences observed under T1 between the different watersheds . In Hampasandra (Kolar) and Honnudeke (Tumkur) watersheds the farmers yield in T1 treatment were very low (1.34 to 1.48 t ha^{-1}) indicating low soil fertility as compared to Huthur (Kolar) and Basethihalli (Kolar) watersheds, where the farmers yield were 2.38 and 2.67 t ha^{-1}, respectively (Table 9B4). The yield enhancement of *ragi* due to improved variety plus improved management ranged from 1.27 to 2.53 t ha^{-1}, which is more than doubling the yields in some watersheds. Where the yield enhancement over the baseline yields was higher, most of it was due to improved soil fertility management (66 to 97%). In the Huthur watershed yield improvement due to variety was greater (69%) than the improved management (31%); whereas in Honnudeke watershed the relative contribution of improved variety and management was equal.

Table 9B4. Yield of *ragi* (t ha^{-1}) in Kolar and Tumkur watersheds.	Watershed in Kolar district			Watershed in Tumkur district
Variety	Hampasandra	Huthur	Basethihalli	Honnudeke
		Treatment 1		
Local	1.48	2.38	2.67	1.34
		Treatment 2		
GPU 28	1.55	2.93	4.28	1.78
MR 1	--	2.31	3.90	2.28
HR 911	--	4.47	2.51	1.75
L 5	--	3.29	3.82	2.45
Mean	1.55	3.25	3.63	2.07
		Treatment 3		
GPU 28	3.10	3.00	6.37	2.27
MR 1	4.07	3.51	5.73	2.43
HR 911	3.56	4.27	4.02	2.81
L 5	5.31	3.81	5.81	3.67
Mean	4.01	3.65	5.48	2.79
% yield increase due to cultivar	3	69	34	50
% yield increase due to management	97	31	66	50

** Mean of 12 farmers in each watershed in Kolar and four farmers in Tumkur districts.*

Evaluation of groundnut varieties in Kolar and Tumkur districts: Table 9B5.. summarizes the yield responses of three groundnut varieties to the three management practices in Hampasandra and Kanakapura watersheds. Yield enhancement due to improved variety ranged from zero up to one tonne, with ICRISAT variety ICGS 91114 producing the highest yields, compared to TMV 2 and JL 24. With improved management (T3), the yield of groundnut doubled when compared with the farmers practice (T1). Total yield enhancement was 1.10 to 1.18 t ha^{-1} with improved practice (T3) as compared to T1. In Hampasandra watershed improved varieties and improved management contributed 28% and 72%, respectively, to the total increase in groundnut yield. Whereas in Kanakapura watershed, relative contribution of improved varieties and management was 60% and 40%, respectively, to the total yield enhancement.

Table 9B. Yield of groundnut varieties (t ha^{-1}) in Kolar and Tumkur watersheds, Karnataka, India

Variety	*Watersheds* Hampasandra (Kolar district)	Kanakapura (Tumkur district)
	Treatment : T1	
Local	1.85	0.91
	Treatment : T2	
TMV 2	1.66	1.10
JL 24	2.23	1.61
ICGS 91114	2.64	1.99
Mean	2.18	1.57
	Treatment : T3	
TMV 2	2.2	1.28
JL 24	3.16	2.43
ICGS 91114	3.73	2.32
Mean	3.03	2.01
% yield increase due to cultivar	28	60
% yield increase due to management	72	40

Evaluation of soybean and sunflower varieties in Chitradurga watershed: Table 9B6 summarizes the yield responses of three varieties of soybean (KHSB 2, MAUS 2 and MACS 124) and four varieties of sunflower (PAC 336, GK 2002, KBSH 41, and KBSH 44) to the three management practices. Soybean variety MACS 124 yielded the maximum in T2, closely followed by other two varieties. Total yield improvement over the farmers' traditional practice (T1) was 50% (0.35 t ha^{-1}). Improved varieties contributed 46% and improved management 54% to the total yield enhancement of soybean.[REF15]

Among the sunflower varieties GK 2002 gave the highest yield, with a 52% improvement in yield due to improved management (T3) compared to farmers practice (T1). Improved varieties contributed 35%, whereas improved management contributed 65% to the total yield increase, indicating the relative importance of management in enhancing yields of soybean and sunflower.

Evaluation of maize varieties in Haveri and Dharwad districts**:** Table 9B7 summarizes the yield responses of four maize varieties to the different management practices for three watersheds. Variety Seedree 740 yielded the maximum in both the T2 and T3 treatments, followed by Proagro 4642. As the farmers in the region are already growing improved cultivars of maize, total yield increase in T3 treatment was only 28% (1.26 t ha^{-1}) over the farmers current practices, which yielded an average of 4.5 t ha^{-1}. Improved management contributed 89% to the total yield increase.

Table 9B6.Yield of soybean and sunflower cultivars in Chitradurga district, Karnataka, India

Soybean variety	Yield (t ha^{-1})	Sunflower variety	Yield (t ha^{-1})
	Treatment : T1		
Local	0.69	Local (Mahyco 17)	0.67
	Treatment : T2		
KHSB 2	0.80	PAC 336	1.09
MAUS 2	0.83	GK 2002	1.12
MACS 124	0.93	KBSH 41	0.97
		KBSH 44	0.95
Mean	0.85		1.03
	Treatment : T3		
KHSB 2	1.19	PAC 336	1.62
MAUS 2	1.20	GK 2002	1.79
MACS 124	0.72	KBSH 41	1.67
		KBSH 44	1.69
Mean	1.04		1.69
% yield increase due to cultivar	46		35
% yield increase due to management	54		65

Table 9B7Yield of maize (t ha^{-1}) cultivars in Haveri district, Karnataka, India

	Watersheds		
Varieties	Chiklinganhalli	Aremellapur	Anchatagiri
	Treatment: T1		
Local (Cargil 900 M)	4.50	4.11	1.73
	Treatment: T2		
GK 3015	4.62	4.71	--
Proagro 4642	4.71	3.34	2.08
Monsanto – all rounder	4.22	4.56	--
Seedree 740	5.00	--	--
Mean	4.64	4.20	2.08
		Treatment: T3	
GK 3015	5.76	6.64	--
Proagro 4642	5.80	5.79	4.83
Monsanto – all rounder	5.30	5.90	--
Seedree 740	6.20	--	--
Mean	5.76	6.11	4.83
% yield increase due to cultivar	11	5	11
% yield increase due to management	89	95	89

9B. 3 Improving Water Productivity in sub-Saharan Africa

I. Effect of minimum tillage and mulching on maize (*Zea mays* L.) yield and water content of clayey and sandy soils. *Walter Mupangwa, Steve Twomlow, Sue Walker and Lewis Hove – ICRISAT and University of the Free State.* Rainfed smallholder agriculture in semi-arid areas of southern Africa is subject to numerous constraints. These include low rainfall with high spatial and temporal variability, and significant loss of soil water through evaporation. An experiment as been established at Matopos Research Station, Zimbabwe, to determine the effect of mulching and minimum tillage on maize yield and soil water content. The experiment as been run for two years and set up at two sites: clay (Matopos Research Station fields) and sand (Lucydale fields) soils, in a 7 x 3 factorial combination of mulch rates (0, 0.5, 1, 2, 4, 8 and 10 t ha^{-1}) and tillage methods (planting basins, ripper tine and conventional plough). Each treatment was replicated three times at each site in a split plot design. Maize residue was applied as mulch before tillage operations. Two maize varieties, a hybrid (SC 403) and an open pollinated variety (ZM 421) were planted. Maize yield and soil water content (0 to 30 and 30 to 60 cm depth) were measured under each treatment. On both soil types, neither mulching nor tillage method had a significant effect on maize grain yield, irrespective of rainfall received (Table 9B8). The three tillage methods had no significant effect on seasonal soil water content, although planting basins harvested more rainwater during the first half of the cropping period. Mulching improved soil water content in both soil types with maximum benefits observed at 4 t ha^{-1} of mulch, although this was not translated into increased yields (Figure 9B5). We conclude that minimum tillage on its own, or in combination with mulching, performs as well as the farmers traditional practices of overall ploughing. The lack of yield response to increased water content may be attributed to the soil fertility management regime followed in this study. Further work is required to look at the interactions between soil water conservation techniques and fertility management regimes.

Table 9B8. Maize yield (kgha^{-1}) and harvest index responses to tillage treatments at Matopos during 2004/05 and 2005/06 cropping seasons

Tillage	**2004/05 season**			**2005/06 season**		
	Grain kg ha^{-1}	**Stover kg ha^{-1}**	**Harvest index**	**Grain kg ha^{-1}**	**Stover kg ha^{-1}**	**Harvest index**
Conventional plough	2616	3649	0.42	2721	6605	0.29
Ripper	2529	3596	0.42	2521	5012	0.28
Planting basin	2441	2808	0.48	3032	6958	0.29
s.e.d.	192	279	0.005	588	1189	0.009

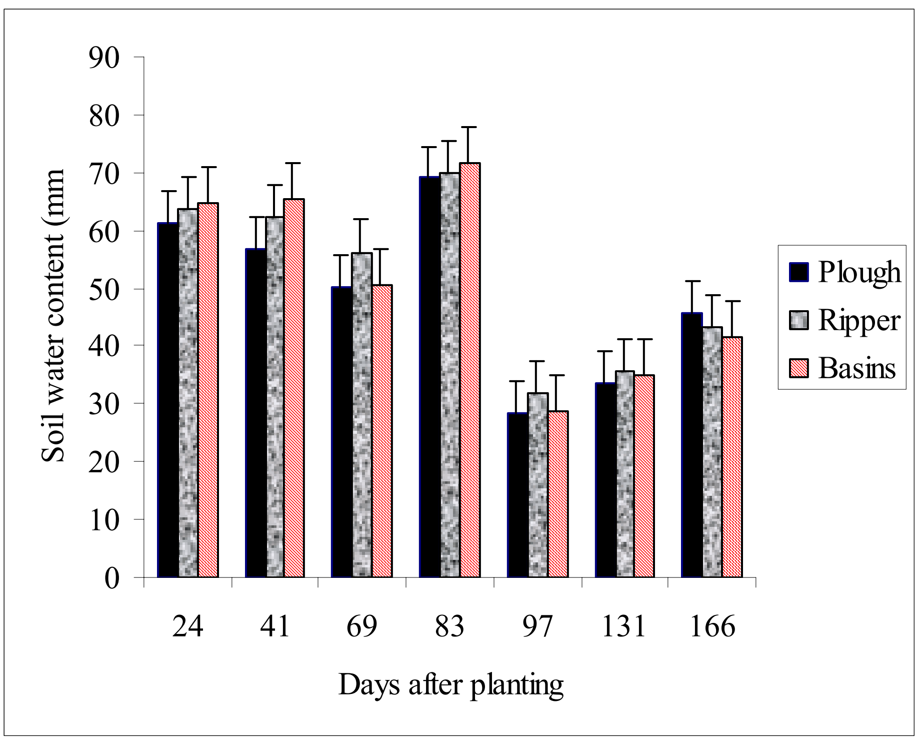


Figure 9B5. Soil water content in the 0 - 0.60 m profile at Lucydale during 2005/06 cropping season. Bars indicate standard error.

ii. **Long Term Trends In Climate And Runoff In The Limpopo Basin, Zimbabwe And Their Livelihood Implications** *David Love, Steve Twomlow, Stefan Uhlenbrook and Pieter van der Zaag - WaterNet, ICRISAT and UNESCO-IHE,*
Rural livelihoods in the Limpopo Basin are made risky by unreliable rainfall, upon which most smallholder farmers depend. Water resource availability constrains our ability to respond to this challenge and analyzing long term trends in climate and runoff can help characterize the constraints.

Climate data for 10 stations (time series of 30 – 70 years) and hydrological data from 30 stations (time series of 25 – 50 years), located across the portion of the Limpopo Basin which lies within Zimbabwe, were analysed to determine the long term trends. Analysis of climate data included evaluation of trends in precipitation and temperature, annual anomalies, depth duration curves, storm intensity analyses, frequency of rainy days and the occurrence of dryspells. Analysis of hydrological data (using normalised flows) included flow duration curves (for undeveloped catchments), flood analyses, days of flow and rainfall-runoff regression analyses.

Results show a decline in rainfall and rise in temperature for some parts of the study area. There is also a decrease in the number of rainy days per season and an increase in the frequency and duration of dry spells during the rainy season from some stations. Analyses of flow data show some rivers with a decline in annual runoff and an increase in the frequency of days with no flow.

The change in rainfall pattern is very significant for rainfed agriculture. The decline in rainfall appears worse for the better agricultural areas in the north. The increase in frequency of dryspells threatens crop failure even in areas with higher rainfall. The effects of these changes on maize yield (as the staple crop) will be simulated using the APSIM model.

Given the significant control of upstream runoff by precipitation received (as shown by the regression analyses), projected declines in rainfall are likely to result in some declines in water availability in the upstream dams. Declines in rainfall may translate to more than proportional declines in runoff due to non-linear processes, including for example interception thresholds. Such a decrease in dam yields will affect both large scale water supply for cities and small dams which supply water to livestock.

iii. Can drip irrigation improve livelihood of smallholders: lessons learned from Zimbabwe
Paul Belder, Aiden Senzanje, Emmanuel Manzungu, Steve Twomlow, David Rohrbach. ICRISAT and University of Zimbabwe
In sub-Saharan Africa it is estimated that one third of the rural population is malnourished, yet the continent's irrigation potential is poorly developed. One intervention, based on successes from Asia, which has potential to improve household nutrition in the rural areas through better vegetable production, is small-scale drip irrigation. This system is said to save water and labour. Since 2002, some 70,000 low-cost, low-head drip irrigation kits have been distributed through humanitarian relief initiatives throughout the rural areas of Zimbabwe.

In the dry season of 2006 a country-wide survey was undertaken to determine the impacts of drip kits that had been delivered to needy households. Survey results showed that disadoption of drip kits occurred as a function of time, and after 3 years only 16% of the kits that had been distributed were still being used (Table 9B9). Reasons for disadoption included lack of water; lack of understanding of the drip kit concept, and more importantly a lack of technical support and follow-up by the Non Government Organizations who distributed the kits and the extension services. A cost-effectiveness analysis showed that drip kits are only more cost-effective than traditional hand watering if potential water savings are achieved (Table 9B10) . This was, however, hardly the case due to lack of knowledge on crop water requirements with the kits, and a beneficiary perception that the soil surface should be wet.

Table 9B9. Utilization of drip irrigation kits by year of distribution in wet and dry season.

Year distributed	Proportion working in dry season of 2006 (N=232)	Proportion working in wet season of 2005/6 (N=232)
2003	15.8	10.5
2004	35.6	22.0
2005	63.6	40.6
2006	100	-

Table 9B10. Approximate costs of drip kit versus bucket irrigation, dry season 2006 (US$)

Cost	Drip irrigation	Bucket irrigation
Kit and spare parts (10m x 10 m)	22	0
Bucket (20 lit)	0	5
Input distribution to farmers	20	10
Labour to manage the vegetable plot	107	124
Total cost	149	139

Consequently, we believe that a relatively complex technology such as drip kits should not be part of short-term relief programs, but be embedded in long-term developmental programs that involve both the public and private sector. This will ensure that appropriate technical support is provided in terms of crop management and the development of supply chains for spare parts and additional kits.

iv. On-farm Yield and Water Use Response of Pearl Millet to Different Management Practices in Niger. *Comfort Manyame, William Payne, James Heilman and Bruno Gerard. ICRISAT and Texas A&M*

Pearl millet production under subsistence farmer management on the sandy soils of southwestern Niger is faced with many challenges, including declining soil fertility, highly variable and scarce rainfall and poor resource base of the peasant farmers in the region. This study was conducted to evaluate the potential of management to increase yield and water use efficiency of pearl millet grown on two farmers' fields in Niger during two growing seasons, 2003 and 2004. The management practices tested were: 1) Five manure treatments (no manure, transported manure, current corralling, a year after corralling, and two years after corralling); 2) The microdose technology (20 kg di-ammonium phosphate ha^{-1}, and 20 kg di-ammonium phosphate ha^{-1} + 10 kg urea ha^{-1}); and lastly, 3) Three different pearl millet cultivars (Heini Kirei, Zatib, and ICMV IS 89305).

In both growing seasons, manure had the greatest effect on the yield and water use of pearl millet at both sites (see Table 9B11 for example). In 2003 grain yields were 389 kg ha-1 in the NM treatment and 1495 kg ha-1 in the C0 treatment at Banizoumbou whereas at Bagoua, the NM treatment had 423 kg ha-1 vs. 995 kg ha-1 in the C0 treatment. In 2004, the NM treatment at Banizoumbou had 123 kg ha-1 grain yield and the C0 treatment had 957 kg ha-1 whereas at Bagoua the NM treatment had 506 kg ha-1 vs. 1152 kg ha-1 in the C0 treatment. Residual effects of manure led to grain yields in the C1 and C2 treatments which were more than twice as high as in the NM treatment. The improved cultivars were generally superior for grain yields, whereas the local landrace was superior for straw yields at both sites. Root zone drainage was decreased by between 50 to 100 mm, and water use increased by the same amount in the current corrals at the two sites during the two growing seasons. Increased water use under corralling and presence of residual profile moisture at the end of each of the two seasons suggested that water did not limit pearl millet production at the two sites.

Table 9B11. Manure effects on the water use efficiencies at Bagoua in 2004. NM is no manure; TM is transported manure; and C1 is one year since last corralling; TDM is total dry matter; and WUE is water use efficiency.

Manure treatment	Grain yield	TDM	WUE (Grain)	WUE (TDM)
kg ha^{-1}	kg ha^{-1}	kg ha^{-1} mm^{-1}	kg ha^{-1} mm^{-1}	
NM	482 ab	1715 ab	1.7 a	6.1 ac
TM	721 bc	2910 cd	2.5 b	9.9 bc
C0	1108 d	3400 e	3.8 c	11.7 d
C1	847 c	2996 de	2.7 b	9.4 bc
C 2	2 610 b	1875 b	2.2 a	6.7 c

†Means followed by the same letter and in the same column are not significantly different with LSD test at 5 % confidence level.
‡WUE=Yield/ET

9 B4. Watershed Interventions in Asia:
i. Runoff and soil loss from on-station watersheds at ICRISAT Center, Patancheru
P Pathak, SP Wani and R sudi
[REF16]
There are two long term watershed trials located on two different soil types at ICRISAT Center, Patancheru, Alfisols (RW2 Watershed) and Vertic Inceptisol (BW7 Watershed) that have the following treatments:

1. Crops and cropping system: Sole sorghum or Groundnut/ Pigeonpea intercrop in rotation with sorghum
2. Management**:** Farmers conventional tillage and fertilizer management practices -Flat land treatment and a series of improved practices that includes a Broad Bed and Furrow (BBF) land treatment.

Total annual rainfall observed in 2005 was 1183 mm, with slight differences in seasonal rainfall observed for the two different soil types, due to differences in planting dates. The seasonal rainfall and the hydrological responses of the two soil types are summarized in Table 9B12 for the Alfisol Watershed and 9B13 for the Vertic Inceptisol Watershed. Although there was no significant difference in runoff between the two land management practices on the Alfisol, soil loss was significantly reduced under the BBF compared to flat land configuration, approximately 28% (Table 9B12).

Table 9B12 . Rainfall, runoff and soil loss from two land treatments at Alfisol (RW2) watershed, 2005.

Parameters	BBF	Flat
Seasonal Rainfall (mm)	1096	1096
Seasonal runoff (mm)	258	275
Peak runoff rate (m^{-3} s^{-1} ha^{-1})	0.158	0.161
Runoff as % of rainfall	23.5	25.0
Total no. of runoff events	16	16
Soil loss (t ha^{-1})	7.10	9.09

The Vertic Inceptisol recorded fewer run off events than the Alfisol, due to later planting date and the higher water holding capacity of this soil. The BBF treatment significantly reduced runoff and soil loss compared to the flat treatments, by 40% and 60% respectively. Peak runoff rate which is responsible for flooding and high soil loss was also significantly lower in BBF when compared with flat system

Table 9B13. Rainfall, runoff and soil loss from two land treatments at Vertic Inceptisol (BW7) watershed, 2005.

Parameters	BBF	Flat
Seasonal rainfall (mm)	1029	1029
Seasonal runoff (mm)	162	227
Peak runoff rate ($m^3 s^{-1} ha^{-1}$)	0.101	0.137
Runoff as % of rainfall	15.8	22.1
Total no. of runoff events	11	11
Soil loss ($t\ ha^{-1}$)	3.70	5.91

ii. Impacts of watershed interventions on water quality

Ch Srinivasarao, SP Wani, KL Sahrawat, P Pathak and G Pardhasaradhi

[REF17]

Quality of water from different water sources, such as tube wells, open wells, hand pumps and dug out ponds was monitored within two watersheds in Madhya Pradesh and Rajasthan during *kharif* 2006. Sampling occurred once in June and once in August. At the same time information was collected on crops/cropping systems/fertilizers/ manures/ pesticides/ tillage/ soil type/ slope etc. of these watersheds. Table 9B14 summarises some of the data collected from the Semli and Syampura watersheds of Madhya Pradesh.

Table 9B14 Concentration (mg L^{-1}) of NO_3-N, sodium, iron and boron in different sources in water at Semli and Shyampura watersheds, Dewas, Madhya Pradesh.

Source of water	Nitrate - Nitrogen	Sodium	Iron	Boron
		June 2006		
Open wells (6)	1.21-8.42 (Nil)*	19-214 (1)	0.03-0.19 (Nil)	0.03-0.30 (1)
Tube wells (6)	1.81-17.74 (4)	21-238 (1)	0.06-0.17 (Nil)	0.15-0.30 (2)
Dugout ponds (6)	1.23-6.14 (Nil)	7-42 (Nil)	0.15-0.31 (1)	0.17-0.30 (1)
		August 2006		
Open wells (6)	2.48-15.04 (2)	9-45 (Nil)	0.05-0.30 (1)	0.12-0.38 (2)
Tube wells (6)	5.29-35.74 (5)	20-235 (1)	0.04-0.40 (2)	0.08-0.41 (3)
Dugout ponds (6)	1.86-4.31 (Nil)	2-29 (Nil)	0.07-0.31 (1)	0.05-0.15 (Nil)

Safety limits: NO_3-N = 10 mg L^{-1}; Sodium = 200 mg L^{-1}; Iron = 0.30 mg L^{-1}; Boron= 0.30 mg L^{-1}

** No of water bodies showed above safety limits*

Similar observations were made in Rajasthan, with some water sources having nitrate levels beyond prescribed safety limits. Some water sources also showed levels of iron and boron beyond the prescribed safety limits for safe drinking water for humans and livestock. It was observed that some of the tube wells and open wells also showed sodium levels above safe limits (>200 mg L^{-1}). However, none of the water bodies showed heavy metal contamination.

9 B5: Eco-friendly pest management strategies for legume-based cropping systems developed.

i. Protecting vegetables on-farm with biological approaches *OP Rupela, GV Ranga Rao, SP Wani and SJ Rahman*

Chemical pesticides remain the first option of most farmers for crop protection. Fruits and vegetables consume 26-28% of the total 2.254 million t of active ingredient of synthetic chemical pesticides produced globally. Pesticide-residues in market samples of vegetables 15 to 20 times higher than the acceptable limits are not uncommon. After 3 years of managing insect-pests on pigeonpea and cotton, using low-cost and biological options in a long-term experiment at ICRISAT Center, similar protocols were evaluated on-farm using cotton as a test crop[REF18]. Seeing success on cotton, the collaborating farmers from two villages (Kothapally and Yellakonda) requested ICRISATs help in protecting vegetable crops (mostly tomato and onion). The experiment was initiated during summer of 2005. The results from the 2-years are reported here. [REF19]

Each participating farmer grew crops on a plot divided into two halves, one half followed the farmers conventional practice (involving synthetic pesticides)-FP, and the other half used low-cost and biological approaches, labeled as 'Bio' using vermiwash from vermicomposting of neem leaves along with other organic residues. Observations were recorded for (a) number of damaged and healthy fruits plant^{-1}, (b) number of spiders' plant^{-1}, (c) number of coccinellids plant^{-1}, (d) yield of whole field/plot and (e) net income from each treatment. Inputs in case of 'Bio' plots were charged at the rate of about Rs. 1700 ha^{-1} (determined by mutual agreement with participant farmers), to ensure involvement of farmers with required seriousness. Data was subjected to statistical analysis, to learn treatment differences where each farmer was treated as replication, in a given village, year and for a given crop.

In 2005, mean yield of the six farmers growing tomato in Kothapally was 56% more (range 2 to 76%) in 'Bio' plots over that in FP (2.45 t ha^{-1}) plots. On average, cost of purchased inputs (agro-chemicals in case of FP) was 22% more than in 'Bio' plots, where net income was more (range 18 to 586%) in Bio than FP plots.

2006 yield data for tomatoes and onions is summarized in Table 9B15. In 2006, onion in the field of Mr S Hanumanth Reddy and tomato in field of Md. Khadir were severely damaged by sucking pests (thrips in onion and aphids in tomato) – both in Kothapally, village and did not recover in the FP plots, despite sprays of synthetic chemicals. These two plots were therefore deleted from statistical analysis. We failed to control damage by thrips in the 'Bio' plots also, but it was much lower than in FP plots. Yield of tomato in 2006 was substantially more than in 2005. Mean yield of the five farmers growing tomato in Kothapally was 30% more in 'Bio' plots (range 13 to 93%) over that in FP (3.83 t ha^{-1}).

Table 9B15 Yield (t ha^{-1}) and net Income (Rs ha^{-1}) in Bio and FP plots of different vegetables, summer 2006

Village name	Crop	Yield (t ha^{-1})		Net income (Rs ha^{-1})	
		Bio	FP	Bio	FP
Kothapally	Tomato	5.74	4.53	19251	12480
	SE±	0.300*$^{(0.066)}$		2009*$^{(0.097)}$	
Kothapally	Onion	9.35	6.67	15236	8070
	SE±	1.08^{NS}		2074^{NS}	
Yellakonda	Onion	15.9	14.3	30432	24431
	SE±	0.592^{NS}		1575*[REF110]	
Yellakonda	Tomato [1]	19.47	24.27	84512	45880
Yellakonda	Chilies [1]	2.64	2.12	60004	44167

Values in the parentheses are F- probabilities; NS= statistically non-significant
**=Statistically significant at 5%,*[REF111] *NS=statistically non-significant; 1=crop was different, therefore not included in the main table for the purpose of statistical analyses*

A new crop of onion was taken for experimentation during 2006 at Kothapally and at the neighboring village Yellakonda. Its mean yield was more (by 40% in Kothapally and by 11% in Yellakonda) in Bio than in FP plots (6.67 t ha^{-1} in Kothapally and 14.3 t ha^{-1} in Yellakonda, Table 9B15). In case of tomato the mean net income was 54.3% more in 'Bio' plots compared to FP plots (mean income Rs. 12479) while in case of onion it was 89% more in 'Bio' plots than FP plots at Kothapally. In Yellakonda, mean net income was 29% more (range 6 to 58%) in Bio plots of onion (Table 9B15) than FP plots (mean Rs. 24430). One plot of chilies was also protected well at Yellkonda where Bio plot yielded 25% more resulting in 36% more net income than that in FP plot.

Spiders and coccinellids were absent in FP plots and ranged only from 0.2 to 0.4 per plant in Bio' plots, compared to about two coccinellids per plant and one spider for every three plants counted in the relevant treatment plots of an experiment at ICRISAT. Large number of sprays in 'Bio' plots (range 6 to 12) were prescribed compared to 'FP' plots (range 2 to 5). A frequent spray in Bio plots was considered necessary until a high population of predators/parasites is ensured.

The results from this exploratory work clearly shows that locally available products can be used to achieve good levels of pest control with additional yield increases.

ii. Integrate, evaluate and promote IDM options with other crop management technologies (including, PVS, IPM INM) for the management BGM of chickpea, and foliar diseases of groundnut in participation with farmers *Suresh Pande and Collaborators*

Farmer-participatory on-farm integrated crop management for the management of BGM of chickpea in Nepal: Chickpea is one of the most important staple grain legumes in Nepal. Despite it importance, at the farm level productivity remains low due to a range of diseases (wilt, botrytis gray mold (BGM)), pests (Helicoverpa Pod borer) and micronutrient deficiencies (boron) that results in poor nodulation. To date each of these constraints have been addressed as a single factor management option, and now need to be integrated, as an integrated crop management (ICM) package, with and emphasis on diseases and pests for the over all management of chickpea crop in Nepal.

In collaboration with Nepal Agricultural Research Council (NARC) and its Regional Research Stations, the ICM technology was evaluated and scaled up in the Terai region of Nepal using participatory technology development approaches involving 369 farmers from seven villages spread across 4 districts. Each evaluation trial was planted on one katha (333 m^2), adjacent to the farmers own crop for direct comparison.

The ICM technology consisted of BGM tolerant cultivar ICC 14344 (Avarodhi)/Tara, a fungicidal seed treatment, wider row spacing, application of Rhizobium innoculant, fertilizer, and judicious use of pesticides to control BGM and pod borer. Plant stand was optimum in ICM plots (~80% germination) compared to non-ICM plots (~50% germination) across all locations. Severity of BGM was very low during the current year in ICM plots due to dry weather and absent of winter rains. Mean grain yield across locations was 1055 kg ha^{-1}.[REF112]

Farmer-participatory on-farm IDM trials in Andhra Pradesh and Karnataka**:** Groundnuts play an important role in the well being of the rural communities of Andhra Pradesh and Karnataka, not only providing essential vegetable protein for household consumption, but also haulms, an essential fodder resource for cattle. Yet, system productivity is severely constrained by two destructive fungal foliar diseases, late leaf spot (*Phaeosariopsis personata*) and rust (*Puccinia arachidis*), that cause severe losses in the quality and quantity (yields) of haulms and pods, impacting on household food security and fodder resources for cattle. Integrated disease management (IDM) packages, developed at ICRISAT-Patancheru, offer simple management solutions to these two diseases.

The IDM package has been promoted widely throughout the states of Andhra Pradesh and Karnataka using participatory technology development approaches involving some 275 farmers from 12 villages. IDM technology consisted of improved duel purpose groundnut cultivar, ICGV 91114 with moderate levels of host plant-resistance, fungicide seed treatment and judicious use of fungicide, chlorothalonil (Kavach) at 60 days after sowing (DAS).

During the 2005/2006[REF113] season, rainfall pattern in the entire Deccan Plateau was unique[REF114], with an early start to the season, that allowed all sowings to be completed by the last week of July. Unfortunately, the post planting period was extremely dry, with little or no rain for most of August. The dry spell was then broken during the last week of August by continuous and heavy rainfall that continued throughout October. Although the crop initially recovered, the continued rainfall during flowering and podding, through to harvest were ideal conditions for foliar diseases, that affected both the quality and quantity of the pods and haulms harvested from non-IDM plots.[REF115]

Mean severity of foliar diseases across locations was low i.e. 6.1 rating on a 1-9 scale) in IDM plots compared to 8.7 rating in non-IDM plots. This reduction in disease severity translated into significantly higher pod (1.48 t ha^{-1} and fodder (2.43 t ha^{-1}) yields across all compared to non IDM plots, where local cultivars were grown (Pod yield 0.77 t ha^{-1} and Haulm yield 1.39 t ha^{-1}).

iii. Farmer-participatory village level seed system for the ICM [REF116]responsive high yielding dual purpose cultivars of chickpea, pigeonpea and groundnut established *Suresh Pande and Collaborators[REF117]*
[REF118]
Access to improved varieties of seed, particularly chickpea, groundnuts and pigeon pea is one of the major constraints to improving overall productivity of these staple grain legumes throughout much of Asia. Typically, resource poor farmers in Asia, and for that matter throughout much of the world, obtain seed from other farmers or purchase from local market close to the time of sowing. If seed systems are not developed to ensure the regular flow of improved germplasm out to the rural communities, all of the crop improvement work will have little impact. Consequently, ICRISAT is working in India and Nepal to help develop community based systems that will ensure a regular flow of improved germplasm into the local markets[REF119]. In fact, seed system development is seen as an integral part of ICRISATs IGNRM approach.

Establishment of village level seed system for groundnut in Anantpur and Kolar districts, India: Groundnut yields are very low in Deccan Plateau due to local cultivars, such as TMV2 that account for 80% of cropped area, that are susceptible to later leaf spot and rusts. Improved cultivars, that have been identified in IDM studies, such as ICGV 91114, are available, and are less susceptible to foliar diseases. Unfortunately the seed is only available in limited amounts, with few people or institutions in Andhra Pradesh or Karnataka having the requisite skills to increase seed production, and hence impact.

Since there is great demand for ICGV 91114, a village level seed multiplication system was established in 12 villages of Anantapur district in collaboration with District Agricultural Advisory and Transfer of Technology Center (DAATTC), ANGRAU-Anantapur, Rural Development Trust (RDT) NGO and in one village in Kolar district in collaboration with RORES during 2005/06 post rainy season.

A total of 164 farmers were involved in seed multiplication of the cultivar ICGV 91114 on 133 ha. The produce was sold to several farmers as seed in these villages as well as in neighboring villages for planting during 2006 rainy season. [REF120]

Establishment of village level seed system for chickpea in Nepal*:* Non-availability of seeds of improved varieties is one of the constraints to improving chickpea production in Nepal. Normally, resource poor farmers obtain seed from other farmers or purchase from local market at the time of sowing. Therefore, to ensure continuous seed supply, we have initiated farmer seed system in collaboration with NGLRP[REF121], Rampur and NORP, Nawalpur for production of improved varieties of chickpea, Avarodhi and Tara during 2005/06 *rabi* season. This system is run by a few expert farmer groups/self help groups (SHG) in the villages.

A total of 12 farmers from four villages participated in the multiplication of the improved cultivars Avarodhi in 83 katha (2.8 ha) and Tara in 20 katha (0.7 ha) during 2005/06 *rabi* season. About 5000 kg seeds of Avarodhi and 1000kg seeds of Tara were produced and sold to other farmers in other districts/villages for expanding chickpea cultivation in 2006.[REF122]

*iv**. Identify, evaluate and promote ICM (IPM/IDM) technologies of legumes for intensifying and diversifying production systems in low (chickpea in rainfed rice fallows) and high (pigeonpea in irrigated rice and wheat cropping system) potential environments[REF123]*** Suresh Pande and Collaborators
In collaboration with the Rice and Wheat Consortium (RWC) and its partner organizations, ICRISAT's extra short duration pigeonpea (ESDP) cultivar, ICPL 88039, was evaluated in farmers fields for resource conservation, grain yield, and suitability for rotation with wheat and to be scaled up for its adoption in the north western plains of India. Crop establishment of ESDP cultivar ICPL 88039 was higher on raised bed planting than traditional flat bed broad casting method and mean grain yield was 23.2% higher.

During the current season ICRISAT-bread ESDP cultivar ICPL 88039 were evaluated for its earliness and yield performance on about 600 ha in north western plains of India and compared with local traditional cultivar UPAS

120. In all the trials ESDP cultivar matured 15-20 days earlier than UPAS 120. Mean grain yield of 1.82 t ha^{-1} was recorded in ESDP cultivar, ICPL 88039 in comparison to 1.35 t ha^{-1} in local cultivar UPAS 120. All the participating and neighboring farmers liked this cultivar for its earliness in maturity in addition to its high yield, tolerance to pod borer, and drought. Since it is maturing two to three weeks earlier than traditional local cultivar UPAS 120, it is well suited for rotation with wheat and thus diversifying rice-wheat cropping system to pigeonpea-wheat cropping system. Our recent surveys indicated that ESDP cultivar, ICPL 88039 has completely replaced local cultivars in district Ghaziabad in Uttar Pradesh and Sonipat in Haryana states.

IRRI-IFAD-IGAU-ICRISAT Collaborative research on introduction of chickpea in the rain fed rice ecosystems in the states of Chattisgarh and Jharkhand, India

Under the activity "Increasing cropping intensity under lowland rice based cropping systems" of an IFAD project, we initiated the identification of suitable cultivars in chickpea for rainfed rice ecosystems in the states of Chattisgarh and Jharkhand, India. On-station and on-farm trials were conducted during the current season in collaboration with Indira Gandhi Agricultural University (IGAU), Raipur, Chattisgarh, Central Rainfed Upland Rice Research Station (CRURRS), and Holy Cross Krishi Vigyan Kendra (HCKVK), Hazaribag, Jharkhand. In the rainfed rice ecosystems of Jharkhand and Chattisgarh, chickpea can be successfully grown utilizing residual soil moisture after rice harvest.

Chhattisgarh: Chickpea varietal trials consisting of seven varieties (ICCV 2, JG 11, JGK1, ICCC37, KAK 2, ICCV 10 and Vaibhav) were conducted in six farmers' fields in the village Kapsada, Mandal Dharsiwa, District Raipur during 2005-06 rabi season. Incidence of wilt was found to be moderate (5 rating on 1-9 scale) in the cultivars JG 11, ICCC 37 and ICCV 10 whereas other cultivars had susceptible (> 7 rating on 1-9 rating scale) reaction. All the cultivars matured between 124 and 130 days after sowing. Highest grain yield was recorded in the cultivar Vaibhav (1246 kg ha^{-1}), followed by ICCV 10 and ICCC 37 (1123 kg ha^{-1}). Farmers accepted all three cultivars as they had low disease incidence and produced higher grain yields under rice-chickpea cropping systems.

Jharkhand: Unlike in Chhattisgarh, the Chickpea varietal trial was conducted in the research farm of Holy Cross Krishi Vignan Kendra, Hazaribag during the current season. Six varieties (ICCV 2, ICCV 10, KAK 2, JG 11, KAK 203R and ICCV 92337) were included in this trial and each cultivar was sown in 200 m^2. Wilt and pod borer were found to be the major biotic constraints for chickpea production in this state. Highest grain yield of 1600 kg ha^{-1} was recorded in the cultivar ICCV 10 followed by 1470 kg ha^{-1} in the cultivar ICCV 2.

Since wilt complex (wilt and root rots) is the major problem in both these states another trial, chickpea wilt and root rots nursery with 30 wilt resistant entries identified at ICRISAT-Patancheru was evaluated in collaboration with Indira Gandhi Agricultural University (IGAU), Raipur, Chattisgarh and Central Rainfed Upland Rice Research Station (CRURRS), Hazaribagh, Jharkhand for identification of wilt resistant high yielding varieties suitable for both these states. Entries of this trial were planted at the research stations in both these locations. In Hazaribagh, Jharkhand, four entries ICCs 12233, 12467, 14404 and 14434 were found resistant by showing < 10% wilt incidence. All these four lines will be evaluated for grain yield during 2006-07 crop season.

v: Rainfed post rainy season cropping in rice fallows of eastern India, Nepal and Bangladesh [REF124]
D Harris, JVDK Kumar Rao, K Mahesh, KD Joshi, NN Khanal, C Johansen, and AM Musa

About 15 million hectares of land in South Asia is left fallow after rainy season rice is harvested. Of this total area, 2.11 million hectares (33% of the *kharif* rice growing area) are to be found in Bangladesh, 0.39 million hectares (26%) in Nepal, with the remaining 11.65 million hectares (29%) of fallow found in India.[REF125] These rice fallows can be used to grow an additional crop to utilize the moisture still left in the soil. As part of DFID/PSRP funded program, technologies to facilitate establishment of chickpea were developed in farmers' fields in the Barind area of NW Bangladesh using participatory research approaches. This technology, comprising short-duration chickpea (as a model post rainy season crop), early sowing, minimum tillage, on-farm seed priming (including supplementation with *Rhizobium* and molybdenum), IPM and protection from grazing has been adopted widely in the Barind and is highly cost-effective. After preliminary constraints and demand analyses were completed in eastern India and the Terai region of Nepal, this package of practices was tested and modified in repeated cycles of participatory action researc[REF126]h. In Nepal, where post rainy season cropping is more common, participatory action research also identified other crops to follow rice, e.g. field peas, lentils, buckwheat and mungbean and some additional technological and resource management options such as IPM and IPNM[REF127] were validated and promoted.

Impact: In India, the survey of 307 farmers in six states of Madhya Pradesh, Uttar Pradesh, Chattisgarh, Orissa, Jharkhand and West Bengal indicates that 60% of farmers had increased the area under chickpea as a result of RRC[REF128] initiatives. Seventy percent of the farmers reported that chickpea cultivation was highly profitable and that their income had increased. The benefit: cost ratio for chickpea cultivation was estimated to about 5.5. Seventy-four percent farmers felt that chickpea cultivation had improved the fertility of the soil and 43% said chickpea cultivation generates substantial additional employment. More than two thirds of the chickpea growers used the additional income to further improve their farming enterprise and to educate their children.

In Nepal, the project brought many positive improvements to the natural resource base. [REF129]For example, there has been a considerable reduction in cattle dung burning, associated improvements in soil fertility and a more efficient utilization of family and womens' labor during slack seasons. Grain legume sales have increased by 220%, whilst household consumption of vegetables and grain legume dal also increased. Over 70% of direct participants and over 40% of the indirect participant farmers reported positive improvement in their access to technological information. The project also strengthened social capital, e.g. a significant number of farmers' groups have been established and strengthened and some of them have been organized into co-operatives for activities such as seed production and marketing of chickpea, rice, mungbean, and also establishing multipurpose agroforestry nurseries. Up to two-thirds of the rice fallow areas of the farmers sampled have been brought under winter and spring crops and cropping intensity has increased up to 205%. Rice, mungbean and chickpea were the three most important crops, and over 50% of participants adopted new varieties and cultivation of mungbean increased by more than 60% in the marginal rainfed areas of project districts.

More than 60% of the direct participants and around 40% of indirect participants have adopted low cost, environmentally friendly, resource augmenting, management technologies and practices, such as seed priming, cow urine sprays, integrated pest management (IPM), integrated plant nutrient systems (IPNS), minimum tillage, improved compost making, and multipurpose tree species on their farms.

In Bangladesh, it was calculated that rainfed chickpea had the lowest costs but the highest benefit: cost ratio (1 : 2.6) of any comparable *rabi* crop, including irrigated boro rice although net returns per the latter crop were higher (but required greater investment). Households in RRC-project areas consumed 30% more chickpeas than other, non-project households and chickpea growers reported that their incomes had increased.

Adoption of earlier maturing rice varieties has increased the productivity of the rice-based systems in each of the three countries by making available extra time for other operations, lower cost of production, reduced use of water and nutrients besides, in some cases, increasing cropping intensity.

Current status: Estimates are that over 11000 households in more than 400 villages in India, more than 300 villages in four districts of Bangladesh and 30000 households in Nepal are currently using elements of the technologies developed during this work. Promotion is being continued by the original NGO partners (CRS, PROVA, FORWARD) in all three countries to the best of their abilities without external funding. For example, in India, CRS is committed to an ambitious plan of expansion involving promotion of the technology in nearly 900 villages during the 2006-07 season. The Chattisgarh state government, following a joint workshop in Raipur with CRS and the National Bank for Agriculture and Rural Development (NABARD) also plans its own promotion program in 2006-07.[REF130]

Project 10
The Virtual Academy for the African and Asian SAT

<u>Output A:</u> ICT-mediated knowledge sharing strategy developed and implemented with partners and online, web-based repository of learning materials designed and developed in the public domain by 2009

Progress towards outputs in 2006:

First draft strategy document prepared. The document proposes an online grid of agricultural education and extension materials covering multiple institutions. This has been further refined through discussions with NARES partners, the Commonwealth of Learning and the University of Florida.

A Strategy document titled "Project AGRID: Establishment of an Agricultural Knowledge Grid to Support Improved Food and Livelihood Security for Farmers in SAT" has been developed and shared with partners and investors.

Approach paper for development of a strategy for the Establishment of an Online Agricultural Knowledge Grid to Support Improved Food, Income and Livelihood Security for Farmers in SAT

In two roundtable consultations organized in February and June 2006 (at ICRISAT, supported by the COL, one attended by the President of COL, Sir John Daniel), a group Vice Chancellors, deans/directors and senior professors from the Indian Institutes of Technology and institutes of higher education in IT agreed that there was a need to form a grid of e-content in agriculture and allied sectors. The grid should be designed such that it serves the content needs of a wide range of stakeholders and should provide learning support to a variety of learners. This is called AGRID. The core technological aspects of the proposed grid, which is a grid of information and learning portals from various organizations have been described by Srivathsan et al. (2004) and these form the initial specifications.

The AGRID will be implemented by a Consortium of partners who will willingly join it and sustain it. The goal of the AGRID consortium is to contribute to improvements in the livelihood, income and food security of farmers through provision of new generation knowledge, learning and information services, and to offer enhanced capacity strengthening and continuing education services to course developers, extension personnel, university students and rural learners.

The principle will be one of cooperative content creation, validation and re-use subject to normal considerations and respect for the intellectual property of the participant institutions. Content re-usability across the English-using countries in South Asia and Sub Saharan Africa will be a key consideration guiding the development of the strategy for AGRID design and deployment.

Objectives:

- Formation and sustenance of a consortium of SAU's, IT resource institutions, ICAR institutes and Divisions and other relevant agencies to participate in the development of a multi-institutional grid of e-content for improved farming and livelihoods.
- Promoting technology-mediated open and distance learning in agriculture to make vocational education accessible to large numbers of rural youth and women.
- Developing capacity strengthening and continuing education programs for teachers, extension personnel and agri-entrepreneurs.
- Building a life-long learning program for farmers for enhanced livelihood security and economic well being, with a special focus on rural women as learners.
- Carry impact assessment studies at all appropriate levels and locations and build a system to internalise stake-holders' feedback.

Specific Objectives:

- Set up a content grid covering 10 participant SAU's and ICAR institutions. The action will begin locally at the participating institutions.
- Strengthen support infrastructure such as web studio and LMS and LCMS in all the participant institutions.
- Develop and validate 2000 hours of vocational ODL material, 500 hours of CE and equivalent of 1000 hours of extension material.
- Enable access to the grid from all the college campuses, field research stations, DL contact centers and KVK's using standard internet connectivity.
- Increase the enrollment in three years in ODL or extension engagement programs and initiate action with a focus on bringing in more women learners.
- Organise specially designed faculty capacity strengthening programs in delivering tech-mediated learning at various levels, and generate 500 hours equivalent online learning material.
- Develop a protocol to allow well-considered outsourcing of administrative and tech management work to capable agencies (pvt/govt)
- Develop 10 IT-mediated rural information outreach centers per participating institute in partnership with CSC and Mission 2007 consortium and test innovative learning and knowledge sharing processes with the stakeholders through them.

Approach:

- Practice of digital repositories of information and learning objects will be followed and global standards such as IMS will be adopted for ease of search and sharing across the participating institutions.
- The repositories will have tools to enable rapid customization of key information at any level, and to deliver such information in print medium or similar others. This will be the key aspect of delivering information to the rural learners and stakeholders in a context specific and relevant manner.
- Strengthening of faculty capacity in production and validation of shareable e-content through online and real-time sessions with relevant experts.
- Enhancing the capacity of extension personnel in the use of online learning and information objects using real-time and online sessions
- Capacity strengthening of ODL personnel in needs assessment, instructional design and monitoring learners' progress with support from domain experts in ODL.
- Rapid production of learning materials for use by mass media using the grid-linked repositories as the source

Outputs and Deliverables:

- New diploma, license and certificate programs covering thousands of new rural and other learners.
- Highly integrated access to learning and extension material covering different languages.
- New continuing education programs for teachers, agri-entrepreneurs, and extension personnel

Outcome:

- The knowledge grid will be a key contribution to further strengthening agriculture extension services.
- Significant improvement in local/rural capacity in information management leads to higher levels of productivity, income, improved access to the markets and better utilisation of public and citizen services at the local level.
- Large scale reduction in the cost of production of development oriented education and information material because of cooperative content creation.
- Unprecedented new opportunities for graduates in agriculture to provide knowledge-based services to a wide range of clients.
- Rapid customization and localisation of generic content will be a key support in disaster preparedness
- A reasonably sized cadre of leaders in information management at various levels starting from the rural extending to the University.
- New synergies built between IT resource organizations, SAU's, extension agencies, media organizations and different national programs.
- New aspects of knowledge management involving PPP would emerge and will be valuable in other sectors in rural development.

This note has been endorsed by nine organizations (including six agricultural universities) in India, and has been presented as the basis for a novel approach to knowledge management in agriculture in India, under the National Agricultural Innovation Project of the Indian Council of Agricultural Research. It has also been accepted as the conceptual framework for content development and distribution by the Global Open Food and Agriculture University and the Imperial College Distance Learning Program associated with the GOAFU. It is under further elaboration to include the practice of Open Educational Resources and Open Standards architecture (joint industry specifications led by IBM and Microsoft) allowing any partner with any kind of online platform to participate in the process of content creation, validation, update and delivery to the learner.

Output B: New approaches for enhanced access to ICRISAT IPG's developed, tested and shared with partners annually

Outputs in 2006:

B 1

Twenty two learning material modules on ICRISAT and VASAT web sites transformed into learning objects mode.

These are available on the VASAT site: www.vasat.org, link to learning resources, then to the following topics: groundnut production practices, crop-weather relationships, soil health.

***B 2**:*

Two workshops organized with partners in assessing the usability of LO's and reports from partners were compiled.

The first one was with IFPRI and Imperial College London (attended by NARES partners and IPGRI-Bioversity) and the second one was under the India Mission 2007 Alliance with NGOs and CBO's.

Reports are now available. One NGO and one CBO partnering ICRISAT on this project presented posters at the CSO-CGIAR Forum (AGM06) based on the workshops held which are also available to partners.

GOFAU/IMPERIAL COLLEGE REPORT ON REUSABLE LEARNING OBJECTS WORKSHOP

(Hosted by ICRISAT, Hyderabad, India, October 6th-7th, 2006)

This workshop was organised with the overall aim of 'developing an RLO Strategy that can be adopted by all content developers and contributors within the GOFAU programme'. A range of different stakeholders (four agricultural universities, one Open University, IFPRI and Bioversity (then IPGRI)) attended this workshop.

The workshop took place over two days, hosted by ICRISAT who provided the venue and logistical support, with sponsorship from Imperial College Distance Learning Programme, through its funding stream associated with the development of an authoring model.

The authoring process was discussed and the attributes that contribute to good quality distance learning materials were reviewed, in the context of quality checklists. The Universities represented had different models for authoring materials. Whilst there were many areas of overlap, the role of academics, assistants, professional writers, learning technologists and instructional designers varied. In some cases the courses produced were very much the teachers own resources, which they had developed. In other cases the writing had been done with an academic supervisor, a contracted author, and possibly a multidisciplinary team, and materials were owned by the programme not the individual. In IGNOU authors were also directly involved in storyboarding and development of additional resources, e.g. e-tutor videos.

The partners involved in development or use of learning materials for both static and dynamic content, could make use of learning resources on the 'grid' and as far as possible reuse and improve grid resources rather than reinvent the wheel. Some partners will be net contributors of RLO content, whilst others will primarily be users.

Questions were raised about the implications of developing RLOs for distance learning programmes in relation to cost, time spent authoring, and whether or not it simplifies or complicates the authoring process. Lessons will be learned by piloting the development of RLOs and it was suggested that all parties moved ahead and developed experience and insights by turning some existing materials into RLOs.

There was a brief discussion reviewing what we need to take into account now, which may be relevant in the future. Specific areas highlighted included:

- Ontologies
- Trends in ODL towards greater use of
    - Reusable content
    - Mobile technologies
    - Blogs and wikis
    - Greater use of multimedia, and delivery approaches such as podcasting and video casting

A concern highlighted was the likelihood that in the medium term there is likely to be even greater diversity in terms of what technologies students in developed/developing and rural/urban areas can access. However the overall trend is increasing scope for an e-learning and m-learning approaches, and as mobile technologies and infrastructure improve, RLOs may become widely accessible.

Content Management Workshops with NGO/CBO's:
Two workshops were organized in collaboration with the India Mission 2007 Alliance during September (Pondicherry) and October (Gujarat) 2006. The participatnts were from large NGO's and media organizations with India-wide presence. In each workshop, about 30 participants joined in, representing about 10 organizations. The focus was on demonstrating a content management platform and the use of RLO's through such a platform. The materials developed on the VASAT project were used as substrates in these exercises. Based on the initiatives of the Mission 2007 Alliance, a significant amount of VASAT material has been translated into Tamil (spoken by about 70 million people) for rendering into learning objects for localization and re-use. Two of these partners subsequently were invited to the CSO-CGIAR forum during the CGIAR annual general meeting (Washington DC, December 2006) where they presented the outcome of these workshops.

Appendix1. List of 2006 Publications

Journal Articles:

Ananada Vadivelu G, Wani, SP, **Bhole, LM**, Pathak, P and **Pande, AB**. 2006. An Empirical Analysis of the Relationship between Land Size, Onership and Soybean Productivity – New Evidence from the Semi-Arid Tropical Region in Madhya Pradesh, India. Journal of SAT Agricultural Research 2 (1): 43. http://www.icrisat.org/journal/agroecosystem/v2i1/v2i1anempirical.pdf.
Anjaiah V and Gabriel DW. 2006. Stable transformation of *Xylella fastidiosa* with small repW shuttle vector pUFR047. Current Science 90(3): 344-347.
Anjaiah V, Thakur RP and Koedam N. 2006. Evaluation of bacteria and *Trichoderma* for biocontrol of pre-harvest seed infection by *Aspergillus flavus* in groundnut. Biocontrol Science and Technology 16:431-436.
ARUNA R and Nigam SN. 2006. Asha - a money spinner in Anantapur. Appropriate Technology 33(4):14-15.
BANTILAN MCS and ANUPAMA KV. 2006. Vulnerability and adaptation in dryland agriculture in India's SAT: experiences from ICRISAT's village-level studies. Journal of SAT Agricultural Research 2(1):14. http://www.icrisat.org/journal/mpii/v2i1/v2i1vulnerability.pdf.
BANTILAN MCS, Chandra S, Keatinge D and **Mehta PK**. 2006. Research quality at ICRISAT: Separating the grain from the chaff. Journal of SAT Agricultural Research 2(1):47. http://www.icrisat.org/journal/mpii/v2i1/v2i1research.pdf.
Berg J van den, **Bronkhorst L,** MGONJA MA and Obilana AB. 2006. Resistance of sorghum varieties to the shoot fly, Atherigona Soccata Rondani (Diptera Muscidae) in Southern Africa. International Journal of Pest Management 51(1):1-5.
Berger JD, **Ali M, Basu PS, Chaudhary BD, Chaturvedi SK, Deshmukh PS, Dharmaraj PS, Dwivedi SK, Gangadhar GC,** Gaur PM, **Kumar J, Pannu RK,** Siddique KHM, **Singh DN, Singh DP, Singh SJ,** Turner NC, **Yadav HS** and **Yadav SS**. 2006. Genotype by environment studies demonstrate the critical role of phenology in adaptation of chickpea (*Cicer arietinum* L.) to high and low yielding environments of India. Field Crops Research 98:230-244.
BHATTACHARJEE R, Khairwal IS, *BRAMEL PAULA J* and Reddy KN. 2006. Establishment of a pearl millet (*Pennisetum glaucum* (L.) R. Br.) core collection based on geographical distribution and quantitative traits. Euphytica (online) http://dx.doi.org/10.1007/s10681-006-9298-x.
Bidinger FR, Bhasker Raj AG and Hash CT. 2006. Zonal adaptation in pearl millet cultivar types. Indian Journal of Genetics and Plant Breeding 66:207-211.
Bidinger FR, *Blummel M* and Hash CT. 2006. Response to recurrent selection for stover feeding value in pearl millet. International Sorghum and Millets Newsletter 47: 113-116.
Blummel M and Parthasarathy Rao P. 2006. Economic value of sorghum stover traded as fodder for urban and peri-urban dairy production in Hyderabad, India. International Sorghum and Pearl Millet News Letter 47: 97-100.
Blummel M and Reddy BVS. 2006. Stover Fodder Quality Traits for Dual-purpose Sorghum Genetic Improvement. International Sorghum and Millets Newsletter 47: 87-89.
Camara Y, BANTILAN MCS and Ndeunga J. 2006. Impacts of sorghum and millet research in West and Central Africa (WCA): A synthesis and lessons learnt. Journal of SAT Agricultural Research 2(1):40. http://www.icrisat.org/journal/mpii/v2i1/v2i1impactsofsorghum.pdf.
Chander Rao S, Kumar PL, Reddy AS, Swamy Krishna T, Waliyar F, Nigam SN, **LAXMINARASU M** and Sharma KK. 2006. Evaluation of transgenic peanut plants against peanut bud necrosis disease (PBND) under greenhouse and field conditions. Indian Journal of Virology 17(2):135.
CHRISTINA ANNA CHERIAN, NALINI MALLIKARJUNA, Deepak Jadhav and Saxena KB. 2006. Open flower segregants selected from *Cajanus platycarpus* crosses. International Chickpea and Pigeonpea Newsletter 13:32-33.
CLARKE HJ, WILSON JG, KUO I, LULSDORF MM, MALLIKARJUNA N, Kuo J and Siddique KHM. 2006. Embryo rescue and plant regeneration *in vitro* of selfed chickpea (*Cicer arietinum* L.) and its wild relatives. Plant Cell, Tissue and Organ Culture 85:197-204.
Craufurd PW, **Prasad PVV**, Waliyar F and *Taheri A.*. 2006. Drought, pod yield, pre-harvest *Aspergillus* infection and aflatoxin contamination on peanut in Niger. Field Crops Research 98:20-29.
CROSER J, LULSDORF M, Davies P, BAYLISS K, MALLIKARJUNA N and Siddique KHM. 2006. Toward doubled haploid production in the Fabaceae: Progress and Constraints, 2006. Critical Reviews in Plant Sciences 25:139-157.
Dar William D, Reddy BVS, Gowda CLL and Ramesh S. 2006. Genetic resources enhancement of ICRISAT mandate crops. Current Science 91(7): 880-884.

Bold=**NARES**; Underline=ARI; Italics= Other *CG Center Scientist*; ALL CAPS=FEMALE SCIENTIST

Journal Articles:

Deb UK and BANTILAN MCS. 2006. Spillover impacts of agricultural research: A review of studies. Journal of SAT Agricultural Research 2(1): 29. http://www.icrisat.org/journal/mpii/v2i1/v2i1spillover.pdf.
DEU M, *Rattunde F* and Chantereau J. 2006. A global view of genetic diversity in cultivated sorghums using a core collection. Genome 49:168-180.
Dhillon MK and Sharma HC. 2006. Effect of storage duration and temperature on viability of eggs of *Helicoverpa armigera* (Lepidoptera: Noctuidae). Bulletin of Entomological Research 96: 1-5.
Dhillon MK, Sharma HC, **Folkertsma RT** and Chandra S. 2006. Genetic divergence and molecular characterization of shoot fly-resistant and -susceptible parents and their hybrids. Euphytica 149:199-210.
Dhillon MK, Sharma HC, Ram Singh and Naresh JS. 2006. Influence of cytoplasmic male-sterility on expression of physico-chemical traits associated with resistance to sorghum shoot fly, *Atherigona soccata*. SABRAO Journal 38(2):105-122.
Dhillon MK, Sharma HC, Reddy BVS, **Ram Singh** and **Naresh JS**. 2006. Inheritance of resistance to sorghum shoot fly, *Atherigona soccata*. Crop Science 46:1377-1383.
Dingkuhn M, Singh BB, Clerget B, Chantereau J and Sultan B. 2006. Past, present and future criteria to breed crops for water-limited environments in West Africa. Agriculture Water Management 80:241-261.
Dubreuil P, *WARBURTON* M, Chastanet M, Hoisington D and Charcosset A. 2006. More on the introduction of temperate maize into Europe: large-scale bulk SSR genotyping and new historical elements. Maydica 51:281-291.
Dwivedi SL, *Blair MW*, Upadhyaya HD, *Serraj R.*, BALAJI J, *BUHARIWALLA HK., Ortiz R* , and *Crouch JH.* 2006. Using genomics to exploit grain legume biodiversity in crop improvement. Plant Breeding Reviews 26:171-358.
Fatondji D, Martius C, Bielders C, Vlek P, Bationo A and Gérard B. 2006. Effect of planting technique and amendment type on pearl millet yield, nutrient uptake, and water use on degraded land in Niger. Nutrient Cycling in Agroecosystems. 76:203-217.
Ganeshamurthy AN, Ali M and Srinivasarao Ch. 2006. Role of pulses in sustaining soil health and crop production. Indian Journal of Fertilizers 1(3):29-40.
Ganeshamurthy AN, Srinivasarao Ch, **Ali M** and **Singh BB**. 2006. Balanced fertilization of greengram (Vigna radiata var radiata) cultivars on a multi-nutrient deficient Typic Ustochrept soil. Indian Journal of Agricultural Sciences 75(4):192-196.
Gaur PM, Pande S, Upadhyaya HD and Rao BV. 2006. Extra-large kabuli chickpea with high resistance to fusarium wilt. Journal of SAT Agricultural Research 2 (1):2. **http://www.icrisat.org/Journal/cropimprovement/v2i1/v2i1extralargekabuli.pdf.**
Githiri SM, Watanabe S, Harada K and Takahashi R. 2006. QTL analysis of flooding tolerance in soybean at an early vegetative growth stage. Plant Breeding 125 (6):613-618.
Godoy R, Wilkie DS, REYES-GARCÍA V, Leonard WR, **Huanca T**, McDade TW, Vadez V and Tanner S. 2006. Human body-mass index (kg/m2) as a useful proxy to assess the relation between income and wildlife consumption in poor rural societies. Biodiversity and Conservation 15 (14):4495-4506.
Gopal Reddy V, Upadhyaya HD and Gowda C.L.L. 2006. Characterization of world foxtail millet germplasm collection for morphological traits. International Sorghum and Millets Newsletter 47:107-109.
Gopal Reddy V, Upadhyaya HD and Gowda CLL. 2006. Current status of sorghum genetic resources at ICRISAT-their sharing and impacts. International Sorghum and Millets Newsletter 47:9-13.
Green PWC, Sharma HC, Stevenson PC and Simmonds MSJ. 2006. Susceptibility of pigeonpea and some of its wild relatives to predation by *Helicoverpa armigera*: implications for breeding resistant cultivars. Australian Journal of Agricultural Research 57:831-836.
Gwata ET, Silim SN and MGONJA M. 2006. Impact of a new source of resistance to fusarium wilt in pigeonpea. Journal of Phytopathology 154:62-64.
HAMEEDA B, **Harish Kumar Reddy Y**, Rupela OP, **Kumar GN** and **Gopal Reddy**. 2006. Effect of carbon substrates on rock phosphate solubilization by bacteria from composts and macrofauna. Current Microbiology 53:298-302.
HAMEEDA B, Rupela OP and **Gopal Reddy**. 2006. Evaluation of bacterial isolates from composts and macrofauna for their biocontrol activity against soil-borne plant pathogenic fungi. Indian Journal of Microbiology 46:389-396.
HAMEEDA B, Rupela OP, **Gopal Reddy** and SATYAVANI K. 2006. Application of plant growth-promoting bacteria associated with composts and macrofauna for growth promotion of Pearl millet (*Pennisetum glaucum* L.). Biology and Fertility of Soils 43:221-227.

Journal Articles:

HAMEEDA B, Rupela OP, Wani SP and **Gopal Reddy**. 2006. Indices to assess soil quality and sustainability in systems involving low cost biological inputs and conventional system. International Journal of Soil Science 1(3): 196-206.
Hash CT, *Blummel M and* Bidinger FR. 2006. Genotype × environment interactions in food-feed traits in pearl millet cultivars. International Sorghum and Millets Newsletter 47:153-157.
Hash CT, Thakur RP, Rao VP and Bhaskar RAG. 2006. Evidence for enhanced resistance to diverse isolates of pearl millet downy mildew through gene pyramiding. International Sorghum and Millets Newsletter 47:134 - 138.
Hatibu N**, Mutabazi K, Senkondo EM** and **Msangi ASK**. 2006. Economics of rainwater harvesting for crop enterprises in semi-arid areas of East Africa**.** Agricultural Water Management 80(1-3):74-86.
HAUSSMANN BIG, **Boubacar A, Boureima SS** and Vigouroux Y. 2006. Multiplication and preliminary characterization of West and Central African pearl millet landraces. International Sorghum and Millet Newsletter 47:110-112.
HAUSSMANN BIG, **Boureima SS** and Bidinger FR. 2006. Evaluation of a medium maturity, high-tillering pearl millet population diallel in Niger. International Sorghum and Millet Newsletter 47:117-119.
Hiraoka Y, Terauchi T, Iwama K, Jitsuyama Y, Kashiwagi J and Gaur PM. 2006. The differences in soil water absorption between four chickpea (*Cicer arietinum* L.) varieties with different root characters. Japanese Journal of Crop Science 221:202-203.
JAYASHREE B, *Crouch JH*, Prasad PVNS and Hoisington D. 2006. A database of annotated tentative orthologs from crop abiotic stress transcripts. Bioinformation 1(6):225-227. Open access: http://www.bioinformation.net/1/57-1-2006.htm
JAYASHREE B, Praveen T Reddy, LEELADEVI Y, *Jonathan H Crouch*, *MAHALAKSHMI V*, HUTOKSHI K BUHARIWALLA, Eshwar K E, EMMA MACE, Rolf Folkertsma, Senthilvel S, Rajeev K Varshney, SEETHA K, RAJALAKSHMI R, Prasanth VP, Chandra S, SWARUPA L, SRIKALYANI P and David A Hoisington. 2006. Laboratory Information Management Software for genotyping workflows: applications in high throughput crop genotyping. BMC Bioinformatics:7:383. Open –access http://www.biomedcentral.com/1471-2105/7/383.
JAYASHREE B, Ramu Punna, Prasad P, Kassahun Bantte, Tom Hash C, Subhash Chandra, David A Hoisington and Rajeev K Varshney. 2006. A database of simple sequence repeats from cereal and legume expressed sequence tags mined *in silico*: survey and evaluation. In Silico Biology 6: 0054. Open access: http://www.bioinfo.de/isb/2006/06/0054/.
KAMALA V, *BRAMEL PJ*, **Sivaramakrishnan S,** Chandra S, KANNAN S, Harikrishna S and **Manohar Rao D.** 2006. Genetic and phenotypic diversity in downy-mildew-resistant sorghum germplasm. Genetic Resources and Crop Evolution 53:1243-1253.
Kant A, Pattanayak D, Chakarbarti SK, Sharma Rajan, Thakur M and Sharma DR. 2006**.** RAPD analysis of variability in *Pinus gerardiana* Wall.- an endangered conifer of North Western Himalayas. Indian Journal of Biotechnology 5: 62-67.
Kashiwagi J, Krishnamurthy L, *Crouch JH and Serraj R*. 2006. Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L) under terminal drought stress. Field Crops Research 95: 171-181.
Kashiwagi J, Krishnamurthy L, Singh S, Gaur PM, Upadhyaya HD, **Panwar JDS, Basu PS**, Ito O and Tobita S. 2006. Relationships between transpiration efficiency and carbon isotope discrimination in chickpea (*C. arietinum* L.). International Chickpea and Pigeonpea Newsletter 13:19-21.
Kashiwagi J, Krishnamurthy L, Singh S and Upadhyaya HD. 2006. Variation of SPAD chlorophyll meter readings (SCMR) in the Mini-core germplasm collection of chickpea. International Chickpea and Pigeonpea Newsletter 13:16-18.
Kaushal RP and Sharma Rajan. 2006. Studies on production and effect of Cercospora toxin and culture filtrates on urdbean and mungbean seed germination. Indian Journal of Pulses Research 19:85-87.
Khairwal IS, Yadav YP and Hash CT. 2006. Evaluation of HHB 67 like pearl millet hybrids under dryland conditions. Annals of Arid Zone 44(1):71–73.
Kileshye Onema J-M, Mazvimavi D, Love D and MUL M. 2006. Effects of selected dams on river flows of Insiza River, Zimbabwe. Physics and Chemistry of the Earth 31:870-875. http://dx.doi.org/10.1016/j.pce.2006.08.022.
Kishore GK, Pande S and **Podile AR**. 2006. *Pseudomonas aeruginosa* GSE 18 inhibits the cell wall degrading enzymes of *Aspergillus niger* and activates defence-related enzymes of groundnut in control of collar rot disease. Australasian Plant Pathology 35:259-263.

Journal Articles:

Kulkarni VN, Rai KN, *Dakheel AJ*, **Ibrahim M** and **Hebbara M**. 2006. Pearl millet germplasm adapted to saline conditions. International Sorghum and Millets Newsletter 47:103–106.
Kumar PL, Jones AT and Waliyar F. 2006. Pigeonpea sterility mosaic disease: challenges in understanding etiology and possible solutions. Indian Journal of Virology 17(2):115.
Kumari AD, Sharma HC and **Reddy DJ**. 2006. Oviposition non-preference as component of resistance to pod borer, *Helicoverpa armigera* in pigeonpea. Journal of Applied Entomology 130:10-14.
Kutywayo V, **Kutywayo D** and Gwata E. 2006. Reaction of cotton and soybean cultivars to populations of *Meloidogyne javanica* and *M. incognita* in Zimbabwe. Journal of Food Agriculture and Environment 4:223-227.
Love D, *Twomlow S, Mupangwa* W, van der Zaag P and **Gumbo B**. 2006. Implementing The Millennium Development Food Security Goals - Challenges Of The Southern African Context. Physics and Chemistry of the Earth 31(15-16):731-737. http://dx.doi.org/10.1016/j.pce.2006.08.002.
LUO GAO-LING, Saxena KB, Kumar RV and YANG SHI-YING. 2006. Analysis and evaluation for the main characteristics of Hybrid Pigeonpea. China seed industry 9:40-50.
LUO GAO-LING, Saxena KB and YANG SHI-YING. 2006. Study on characteristics of flowering and pod-setting in pigeonpea. Seed. 25(9):55-56.
MACE ES, **Phong DT**, Upadhyaya HD, Chandra S and *Crouch JH*. 2006. SSR analysis of cultivated groundnut (*Arachis hypogaea* L.) germplasm resistant to rust and late leaf spot diseases. Euphytica 152:317-330.
MADHAVI LATHA, K. 2006. Book Review: Breeding field crops. Fifth edition. David A. Sleper and John M. Poehlman. Journal of SAT Agricultural Research 2(1):2. http://www.icrisat.org/journal/cropimprovement/v2i1/v2i1-bookreview.pdf.
Mallikarjuna Swamy BP, Upadhyaya HD and **Kenchana Goudar PV**. 2006. Characterization of Asian core-collection of groundnut for morphological traits. Indian Journal of Crop Science 1:129-134.
Mariac C, LUONG V, **Kapran I**, **MAMADOU A**, Sagnard F, DEU M, Chantereau J, Gérard B, Ndjeunga J, Bezancon G, Pham JL and Vigouroux Y. 2006. Diversity of wild and cultivated pearl millet accessions (Pennisetum glaucum [L.] R. Br.) in Niger assessed by microsatellite markers. Theoretical and Applied Genetics 114:49-58.
MATI BM, Morgan RPC and Quinton JN. 2006. Soil erosion modeling with EUROSEM at Embori and Mukogodo catchments, Kenya. Earth Surface Processes and Landforms 31:579-588.
MGONJA MA, Chandra S, Monyo ES, Obilana AB, **Chisi M, Saadan HM**, KUDITA S and CHINHEMA E. 2006. Stratification of SADC regional sorghum testing sites based on grain yield of varieties. Field Crops Research 96(11):25-30.
MILLAN T, CLARKE HJ, Siddique KHM, BUHARIWALLA HK, Gaur PM, Kumar J, Gil J, Kahl G and Winter P. 2006. Chickpea molecular breeding: New tools and concepts. Euphytica 147:81-103.
Moyce W, Owen R, Mangeya P and Love D. 2006. Alluvial aquifers in the Mzingwane Catchment: their distribution, properties, current usage and potential expansion. Physics and Chemistry of the Earth 31, 988-994. http://dx.doi.org/10.1016/j.pce.2006.08.013.
Moyo R, Love D, MUL M, Mupangwa W and Twomlow S. 2006. Impact and sustainability of low-head drip irrigation kits, in the semi-arid Gwanda and Beitbridge Districts, Mzingwane Catchment, Limpopo Basin, Zimbabwe. Physics and Chemistry of the Earth 31:885-892. http://dx.doi.org/10.1016/j.pce.2006.08.020.
Msangi S, RINGLER C and Rosegrant MW. 2006. Doing the Right thing with water: combining market-based principles with policy intervention for sustainable management of water in agriculture. CAB Reviews Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 1(37): 13.
Msangi S, Rosegrant MW and You L. 2006. Ex Post assessment methods of climate forecast impacts. Climate Research 33(1):67-99.
Mupangwa W, Love D and Twomlow S. 2006. Soil–water conservation and rainwater harvesting strategies in the semi-arid Mzingwane Catchment, Limpopo Basin, Zimbabwe. Physics and Chemistry of the Earth 31: 893-900. http://dx.doi.org/10.1016/j.pce.2006.08.042.
Nagaraj KM, Chikkadevaiah, Muniyappa V, Rangaswamy KT and Kumar PL. 2006. Evaluation of pigeonpea genotypes for resistance to Pigeonpea sterility mosaic virus – B isolate. Indian Journal of Plant Protection 34:2.
NALINI MALLIKARJUNA**,** Deepak Jadhav and **Prabhakar Reddy**. 2006. Introgression of *Cajanus platycarpus* genome into *C. cajan*. Euphytica149: 161-167.
NALINI MALLIKARJUNA and **Sunil kumar Tandra**. 2006. Use of 2n pollen in generating interspecific derivatives of groundnut. International Arachis Neswletter 26:8-10.
NALINI MALLIKARJUNA, **Sunil Kumar Tandra** and Deepak Jadhav. 2006. *Arachis hoehnei*, the probable B genome donor of *A. hypogaea*. International Arachis Neswletter 26:10-11.

Journal Articles:

NAMITA SRIVASTAVA, Vadez V, Upadhyaya HD and Saxena KB. 2006. Screening for intra and inter specific variability for salinity tolerance in Pigeonpea (Cajanus cajan) and its related wild species. Journal of SAT Agricultural Research. 2(1):12. http://icrtest:8080/Journal/cropimprovement/v2i1/v2i1screeningfor.pdf.
Nare L, Love D and **Hoko Z.**. 2006. Involvement of stakeholders in the water quality monitoring and surveillance system: the case of Mzingwane Catchment. Physics and Chemistry of the Earth 31(15-16):707-712. http://dx.doi.org/10.1016/j.pce.2006.08.037.
Navi SS, **Tonapi VA**, **Varanavasiappan S**, Reddy, RCh. 2006. Host plant resistance to grain mold in germplasm accessions of pearl millet [Pennisetum glaucum (L.) R. BR.]. Archives of Phytopathology and Plant Protection 39(6):465-477.
Nayyar H, SATWINDER KKAUR, **SMITA SINGH** and Upadhyaya HD. 2006. Differential sensitivity of desi (small-seeded) and kabuli (bold-seeded) chickpea genotypes to water stress during seed filling: Effects on accumulation of seed reserve and yield. Journal of the Science of Food and Agriculture 86:2076-2082.
Nayyar H, **SMITA SINGH**, **SATWINDER KAUR**, **Kumar S** and Upadhyaya HD. 2006. Differential sensitivity of Macrocarpa and microcarpa types of chickpea (*Cicer arietinum* L.) to water stress: Association of contrasting stress response with oxidative injury. Journal of Integrative Plant Biology 48:1318-1329.
Nepolean T, *Blümmel M*, Bhasker Raj AG, **Rajaram V**, Senthilvel S and Hash CT. 2006. QTLs controlling yield and stover quality traits in pearl millet. International Sorghum and Millets Newsletter 47: 149-152.
Ntare BR, Waliyar F, Mayeux AH and Bissala HY. 2006. Strengthening conservation and utilization of groundnut (*Arachis hypogeae* L.) genetic resources in West Africa. Plant Genetic Resources Newsletter 147:1-7.
Okello JJ and Swinton SM. 2006. Do international food safety standards marginalize the poor? Evidence from Kenya's green bean family farmers. Journal of Food Distribution and Research 37(1)18 (March 2006) – Research Update.
PADMAJA KV, SP Wani, **Lav Agarwal** and *KL Sahrawat*. 2006. Economic assessment of desilted sediment in terms of plant nutrients equivalent: A case study in the Medak district of Andhra Pradesh**.** Journal of SAT Agricultural Research 2(1): 21 pp http://www.icrisat.org/Journal/agroecosystem/v2i1/v2i1economic.pdf
Pande S, Galloway J, Gaur PM, Siddique KHM, **Tripathi HS**, Taylor P, MacLeod MWJ, **Basandrai AK**, Bakr A, **Joshi S**, Krishna Kishore G, Isenegger DA, Narayana Rao J and SHARMA M. 2006. Botrytis grey mould of chickpea: A review of biology, epidemiology and disease management. Australian Journal of Agricultural Research 57:1137-1150.
Pande S, Krishna Kishore G, Upadhyaya HD and Narayana Rao J. 2006. Identification of sources of multiple disease resistance in mini-core collection of chickpea. Plant disease 90:1214-1218.
Pande S, Pathak M, SHARMA M, Narayana Rao J, **Anil Kumar J**, **Madhusudan Reddy D**, **Benagi VI**, **Mahalinga D**, **Zhote KK**, **Karanjkar PN** and **Eksinghe BS**. 2006. Outbreak of Phytophthora Blight of Pigeonpea in the Deccan Plateau of India, 2005. International Chickpea and Pigeonpea Newsletter 13:40-42.
Pande S, Pathak M, SHARMA M, Narayana Rao J and Tomar OS. 2006. Resistance to Phytophthora Blight in the improved pigeonpea lines at ICRISAT, Patancheru, India. International Chickpea and Pigeonpea Newsletter 13:42-44.
Pande S, Ramgopal D, Kishore GK, MALLIKARJUNA N, SHARMA M, Pathak M and Narayana Rao J. 2006. Evaluation of wild *Cicer* species for resistance to Ascochyta blight and Botrytis gray mold in controlled environment at ICRISAT, Patancheru, India. International Chickpea and Pigeonpea Newsletter 13:25-27.
Pande S, SHARMA M, Pathak M and Narayana Rao J. 2006.Comparison of Greenhouse and Field Screening Techniques for Botrytis Gray Mold Resistance. International Chickpea and Pigeonpea Newsletter 13:27-29.
Parthasarathy Rao P, **Birthal PS** and **Joshi PK**. 2006. Diversification of agriculture towards high value commodities: role of urbanization and infrastructure. Economic and Political Weekly XLI (26):2747-2753.
Parthasarathy Rao P, **Birthal PS**, Reddy BVS, Rai KN and Ramesh S. 2006. Diagnostics of sorghum and pearl millet grain based nutrition. International Sorghum and Pearl Millet News Letter 47: 93-96.
Pasternak D, Nikiema A, Senbeto D, Dougbedji F and Woltering L. 2006. Intensification and Improvement of Market Gardening in the Sudano-Sahel Region of Africa. Chronica Horticulturae 40(4):44-48.
Pathak P, Wani, SP, Piara Singh, Sudi R and Srinivasa Rao Ch. 2006. Hydrological Characterization of Benchmark Agricultural Watersheds in India, Thailand and Vietnam. Journal of SAT Agricultural Research 2(1): 47 pp. http://www.icrisat.org/Journal/agroecosystem/v2i1/v2i1hydrological.pdf
Pathak P, Wani SP and Sudi R. 2006. Gully Control in SAT Watersheds. Journal of SAT Agricultural Research, Journal of SAT Agricultural Research 2(1): 23. http://www.icrisat.org/Journal/agroecosystem/v2i1/v2i1gully.pdf.

Journal Articles:

Piara Singh, D VIJAYA, K. Srinivas, and S P. Wani. 2006. Potential Productivity, Yield Gap, and Water Balance of Soybean-Chickpea Sequential System at Selected Benchmark Sites in India. Journal of SAT Agriculture Research. 2(1): 50 pp http://www.icrisat.org/Journal/agroecosystem/v2i1/v2i1potential.pdf
Piara Singh, D VIJAYA, **N T CHINH, Aroon Pongkanjana,** K S Prasad, K Srinivas, and S P Wani. 2006. Potential productivity and Yield gap of Selected Crops in the Rainfed Regions of India, Thailand and Vietnam. . Journal of SAT Agriculture Research. 2(1) : 34 pp.http://www.icrisat.org/journal/agroecosystem/v2i1/v2i1potpro.pdf
Pratap Narain, Wani SP and **Singh SK**. 2006. Strategies for Improving Soil and Water Quality in Arid and Rainfed Agro-ecosystems of India *in* Proceedings of International Conference on Soil and Water Environmental Quality – Issues and Strategies. Indian Society of Soil Science 441-452.
PUSHPAVATHI B, Thakur RP, **Chandrashekara Rao K** and Rao VP. 2006. Characterization of *Sclerospora graminicola* isolates from pearl millet for virulence and genetic diversity. Plant Pathology Journal 22:28-35.
PUSHPAVATHI B, Thakur RP and **Chandrashekara Rao K**. 2006. Fertility and mating type frequency in Indian isolates of *Sclerospora graminicola*, the downy mildew pathogen of pearl millet. Plant Disease 90:211-214.
PUSHPAVATHI B, Thakur RP and **Chandrashekara Rao K.** 2006. Inheritance of avirulence in *Sclerospora graminicola*, the pearl millet downy mildew pathogen. Plant Pathology (e-Journal) 5:54-59.
Ramakrishna A, **Hoang Minh Tam**, Wani SP and **Tranh Dinh Long**. 2006. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crops Research 95:115-125.
Ramesh S, Reddy BVS, SANJANA REDDY P and Ramaiah B. 2006. Influence of CMS on agronomic performance of sorghum hybrids. International Sorghum and Millets Newsletter 47:21-25.
Ranga Rao GV. 2006. Integrated Pest Management: Neem: the bitter truth. Appropriate Technology 33(3):29.
Ranga Rao GV, **NGO THI LAM GIANG**, **Phan Lieu** and **NGUYEN THI HOAI TRAM.** 2006. Occurrence of Grubs in Groundnut Crop in Uplands of South Vietnam: A NewReport. International Arachis Newsletter 26: 29-31.
Ranga Rao GV, **SIREESHA K** and Lava Kumar P. 2006. Role of nucleo polyhedron viruses in the management of *Helicoverpa armigera* Hubner: Current status and future prospects 2006. Indian Journal of Virology 17(2):156-157.
Rao KPC, Kumara Charyulu D and UMADEVI K. 2006 Monitoring of Agrarian Changes through Household Panels: VLS Approach. Asian Economic Review 48(3):439-455.
Rao VP, Thakur RP, Singh AK and Rai KN. 2006. Evaluation of pearl millet male-sterile lines and their maintainers for resistance to downy mildew and smut. International Sorghum and Millets Newsletter 47:131-133.
Rathour R, Sharma Rajan and Sharma V. 2006. Genetic differentiation of rice and non-rice populations of *Magnaporthe grisea* from north-western Himalayas using native protein and isozyme polymorphisms. Journal of Phytopathology 154: 641-647.
Ravinder Reddy Ch, **Vilas A Tonapi, Varanavasiappan S**, Navi SS and Jayarajan R. 2006. Influence of plant age on infection and symptomatological studies on urd bean leaf crinkle virus in urd bean (*vigna mungo*). International Journal of Agricultural sciences I:1-6.
Ravinder Reddy Ch, **Vilas A Tonapi, Varanavasiappan S**, Navi SS and Jayarajan R. 2006. Management of urd bean leaf crinkle virus in urd bean (*Vigna mungo*). International journal of Agricultural sciences. II (1):22-28.
Reddy AS, Kumar PL, Nigam SN and Waliyar F. 2006. Effect of virus titer and date of inoculation on infectivity of Peanut bud necrosis (PBNV), Tobacco Streak virus (TSV), and Indian Peanut clump virus (IPCV) to groundnut. Indian Journal of Virology 17(2):146.
Reddy BVS, Sharma HC, Thakur RP and **Ramesh S**. 2006. Characterization of ICRISAT-Bred Sorghum Hybrid Parents Research. Special Issue. International Sorghum and Millets Newsletter 47: 1-21.
Reddy BVS, Sharma HC, Thakur RP and **Ramesh S**, Fred Rattunde and MARY MGONJA. 2006. Sorghum Hybrid Parents Research at ICRISAT–Retrospect and Prospects. International Sorghum and Millets Newsletter 47:26-29.
Reddy BVS, Sharma HC, Thakur RP, **Ramesh S**, Fred Rattunde and MARY MGONJA. 2006. Sorghum Hybrid Parents Research at ICRISAT–Strategies, Status and Impacts. Journal of SAT Agricultural Research 2 (1):1-24. http://www.icrisat.org/journal/cropimprovement/v2i1/v2i1sorghumhybrid.pdf
Reddy BVS, Thakur RP, **Ramesh S**, Rao VP and SANJANA REDDY P. 2006. Effects of cytoplasmic-nuclear male-sterility systems on sorghum grain mold development. International Sorghum and Millets Newsletter 47:16-20.

Journal Articles:

Reddy V Ratna and **Behera B**. 2006. Impact of Water Pollution on Rural Communities: An Economic Analysis, (jointly). Ecological Economics (Elsevier) 58(3):520-537.
Reddy V Ratna, **Juha U**, Frans DR and **MATIN N**. 2006. Achieving Global Environmental Benefits Through Local Development of Clean Energy: The Case of Small Hilly Hydel in India (jointly). Energy Policy (Elsevier) 34:4069-4080.
Reddy V Ratna, **Kumar U Hemant** and **Rao D Mohana**. 2006. Participatory Watershed Development and the Role of Project Implementing Agency (PIA): The Experience of Andhra Pradesh (jointly). Journal of Rural Development 25(3):363-394.
Reddy KN, Upadhyaya HD, Reddy LJ and Gowda CLL. 2006. Evaluation of pollination control methods for pigeonpea [*Cajanus cajan* (L.) Millsp.] germplasm regeneration. International Chickpea and Pigeonpea Newsletter 13:35-38.
Reif JC, *WARBURTON* ML, Xia XC, Hoisington DA, *Crossa J, Taba* S, Muminovic J, Bohn M Frisch M and Melchinger AE. 2006. Grouping of accessions of Mexican races of maize revisited with SSR markers. Theoretical and Applied Genetics 113:177-185.
REYES-GARCÍA V, **Huanta T**, Vadez v, Leonard WR and Wilkie Cultural D. 2006. Practical, and economic value of wild plants: A quantitative study in the Bolivian Amazon. Economic Botany 60 (1):62-74.
RINGLER C, Van Huy N and Msangi S. 2006. Water allocation policy modeling for the Dong Nai river basin: An integrated perspective. Journal of the American Water Resources Association 42(6):1465-1482.
Rusike J, Twomlow SJ, Freeman HA and Heinrich GM. 2006. Does farmer participatory research matter for improved soil fertility technology development and dissemination in Southern Africa? International Journal Of Agricultural Sustainability 4(2):1-17.
Sahrawat KL. 2006. Fresh water shortage and strategy for wetland rice cultivation. Current Science 90:1458.
Sahrawat KL. 2006. Organic matter and mineralizable nitrogen relationships in wetland rice soils. Communications in Soil Science and Plant Analysis 37:787-796.
Sastry DVSSR, Reddy KN, Upadhyaya HD and Gowda CLL. 2006. ICP 13828- a pigeonpea germplasm accession for 10-seeded pods. International Chickpea and Pigeonpea Newsletter 13:34.
Sastry DVSSR, Upadhyaya HD and Gowda CLL. 2006. Degluming, storage and testing periods influencing seed germination of wild sorghum. International Sorghum and Millets Newsletter 47:5-8.
Saxena KB. 2006. Hybrid seed production system in pigeonpea. Asian Seed and Planting Material 13(4):10-12.
Saxena KB, Kumar RV, MADHAVI LATHA K and **Dalvi VA**. 2006. Commercial pigeonpea hybrids are just a few steps away. Indian Journal of Pulses Research 19(1):7– 16.
Shambu Prasad, LAXMI C T and Wani SP 2006. Institutional Learning and Change (ILAC) at ICRISAT: A Case Study of the Tata-ICRISAT Project. Journal of SAT Agricultural Research. 2(1):39. http://www.icrisat.org/journal/agroecosystem/v2i1/v2i1instutional.pdf.
Sharma HC, Dhillon MK and Reddy BVS. 2006. Expression of resistance to sorghum shoot fly in F_1 hybrids involving shoot fly resistant and susceptible cytoplasmic male-sterile and restorer lines of sorghum. Plant Breeding 125: 473-477.
Sharma HC and Pampapathy G. 2006. Influence of transgenic cotton on the relative abundance and damage by the target and non-target insect pests under different protection regimes in India. Crop Protection 25:800-813.
Sharma HC, Pampapathy G and Wani SP. 2006. Influence of host plant resistance on biocontrol of *Helicoverpa armigera* in pigeonpea. Indian Journal of Plant Protection 34:129-131.
Sharma KK, LAVANYA M and Anjaiah V. 2006. *Agrobacterium*-mediated production of transgenic pigeonpea (*Cajanus cajan* L. Millsp.) expressing the synthetic *Bt cry1Ab* gene. In Vitro Cellular & Developmental Biology-Plant 42:165-173.
Sharma KK, Kumar PL, Waliyar F, Nigam SN, LAVANYA M, Reddy AS and Swamy Krishna T. 2006. Development and evaluation of transgenic peanuts for induced resistance to the Indian peanut clump virus. Indian Journal of Virology 17(2):112.
SHARMA POOJA, Sharma KD, Sharma Rajan and Plaha P. 2006. Characterization of *Fusarium oxysporum* f.sp. *pisi* isolates of North-Western Himalayas using morphological and molecular markers. Indian Journal of Biotechnology 5: 298-302.
Sharma YK, Rao VP, Thakur RP and Rai KN. 2006. Efficiency of pathotype mixture in screening for downy mildew resistance in pearl millet. International Sorghum and Millets Newsletter 47:139-142.
Sheshshayee MS, BINDUMADHAVA H, Rachaputi NR, **Prasad TG, Udayakumar M,** Wright GC and Nigam SN. 2006. Leaf chlorophyll concentration relates to transpiration efficiency in peanut. Annals of Applied Biology 148:7-15.

Journal Articles:

Shiferaw B, **Obare G** and Muricho G. 2006. Rural Institutions and Producer Organizations in Imperfect Markets: Experiences from Producer Marketing Groups in Semi-Arid Eastern Kenya. Journal of SAT Agricultural Research. 2(1):37. http://www.icrisat.org/journal/mpii/v2i1/v2i1rural.pdf.
Silim SN, *Coe R.*, **Omanga,PA** and Gwata ET. 2006. The response of pigeonpea genotypes of different duration types to Variation in Temperature and photoperiod under field conditions in Kenya. Journal of Food, Agriculture and Environment 4:209-214.
Singh SN, Jyothirmai VK, Anil Kumar B and Reddy YVR. 2006. Economic Evaluation of Watershed Development Programs in Semi-Arid Regions of India - Viability, Acceptability and Emerging Issues. Asian Economic Review 48(3):387-403.
Somado EA, Sahrawat KL and Kuehne RF. 2006. Rock phosphate-P enhances biomass and nitrogen accumulation by legumes in upland crop production systems. Biology and Fertility of soils 43:124-130.
SREEDEVI TK, Wani, SP, Sudi R, Patel MS, Jayesh T, Singh SN and Tushahr Shah. 2006. On-site and Off-site Impact of Watershed Development: A Case Study of Rajasamadhiyala, Gujarat, India. Journal of SAT Agricultural Research. 2(1):48. http://www.icrisat.org/journal/agroecosystem/v2i1/v2i1on-site.pdf.
Sreenath Dixit, Wani SP, Ravinder Reddy Ch, **Somnath Roy**, Reddy, BVS, Sreedevi TK, **Chourasia AK**, Pathak P, Rama Rao M and Ramakrishna A. 2006. Participatory Varietal Selection and Village Seed Banks for Self-Reliance: Lessons Learnt. Journal of SAT Agricultural Research 2 (1):15 http://www.icrisat.org/journal/agroecosystem/v2i1/v2i1parvar.pdf.
Sreenivasulu P, Ramesh B and Kumar PL. 2006. Vector-borne viruses of banana and plantain (*Musa* spp.) occurring in semi-arid tropics. Indian Journal of Virology 17(2):115.
Srinivasarao Ch., **Basu PS**, **Venkateswarlu B** and **Ali M**. 2006. Variations in nodulation and nitrogen uptake in twenty chickpea genotypes under rainfed conditions. Indian Journal of Dryland Agricultural Research and Development 21:50-52.
Srinivasarao Ch, **Ganeshamurthy AN**, **Massod Ali** and **Singh RN**. **2006**. Phosphorus and micronutrient nutrition of twenty chickpea genotypes on multi-nutrient deficient Typic Ustochrept. Journal of Plant Nutrition (USA) 747-763.
Srinivasarao Ch**,** RUPATR, **Subba Rao**, **Singh SP** and **Bansal SK**. 2006. Kinetics of nonexchangeable potassium release from important benchmark soils of India: Effects of mineralogy, soil depth and extraction media. Communications in Soil Science and Plant Analysis 36(3&4):1-19.
Srinivasarao Ch, **Vittal KPR, Chary GR, Gajbhiye PN** and **Venkateswarlu B**. 2006. Characterization of available major nutrients in dominant soils of rainfed crop production systems of India. Journal of Dryland Agricultural Research and Development 21:105-113.
Srinivasan S, Gaur PM, **Chaturvedi SK** and Rao BV. 2006. Allelic relationships of genes controlling number of flowers per axis in chickpea. Euphytica 152:331-337.
Srinivasan S, Gaur PM and Rao BV. 2006. Relationships of pinnate (fern) and simple (unifoliate) leaf traits with seed yield and seed size in kabuli chickpea. Journal of SAT Agricultural Research 2 (1):2. http://www.icrisat.org/Journal/cropimprovement/v2i1/v2i1relationships.pdf
SRIVASTAVA N, Vadez V, Upadhyaya HD and Saxena KB. 2006. Screening for intra and inter specific variability for salinity tolerance in Pigeonpea (*Cajanus cajan*) and its related wild species. Journal of SAT Agricultural Research 2:12. http://www.icrisat.org/journal/cropimprovement/v2i1/v2i1screeningfor.pdf.
Subbarao GV, Ito O, Sahrawat KL, Berry WL, Nakahara K, Ishikawa T, Watanabe T, Suenaga K, *Rondon* M and *Rao IM*. 2006. Scope and strategies for regulation of nitrification in agricultural systems—challenges and opportunities. Critical Reviews in Plant Sciences 25:303-335.
Sudhakara Babu SN and PADMAJA KV. 2006. Intercropping systems involving castor in India - A review. Journal of Oilseeds Research 23(1):8-15.
Thakur RP, **Shetty HS** and **Khairwal IS**. 2006. Pearl millet downy mildew research in India: progress and perspectives. International Sorghum and Millets Newsletter 47:125-130.
Thornton P, Ly S, Notenbaert A, Stroud A, Twomlow S, von Kaufman R, . Kruska R, Hatibu N, *Legg C* and **Molapong K**. 2006. Site selection to test an integrated approach to agricultural research for development: combining expert knowledge and participatory Geographic Information System methods. International Journal of Agricultural Sustainability 4(1):1-22. http://www.sciencedirect.com/science?_ob=PublicationURL&_tockey=%23TOC%234958%232006%23999199998%23615859%23FLA%23&_auth=y&view=c&_acct=C000001618&_version=1&_urlVersion=0&_userid=995675&_pubType=J&md5=fac3dd797b51bc9442516a937df4b40e
Upadhyaya HD, COYNE JC, Singh S, Gowda CLL, LALITHA N and Muehlbauer FJ. 2006. Identification of large-seeded high-yielding diverse kabuli accessions in newly assembled germplasm. International Chickpea and Pigeonpea Newsletter 13:2-5.

Journal Articles:

Upadhyaya HD, *FURMAN BJ,* Dwivedi SL, *Udupa SM,* Gowda, CLL, *Baum M, Crouch JH, BUHARIWALLA HK,* and Sube Singh. 2006. Development of a composite collection for mining germplasm possessing allelic variation for beneficial traits in chickpea. Plant Genetic Resources 4:13-19.
Upadhyaya HD, Gowda CLL, *BUHARIWALLA HK,* and *Crouch JH.* 2006. Efficient use of crop germplasm resources: identifying useful germplasm for crop improvement through core and mini core subsets and molecular marker approaches. Plant Genetic Resources 4:25-35.
Upadhyaya HD, Gowda CLL, Pundir RPS, Reddy VG and Sube Singh. 2006. Development of core subset of finger millet germplasm using geographical origin and data on 14 quantitative traits. Genetic Resources and Crop Evolution 53:679-685.
Upadhyaya HD, Reddy LJ, Gowda CLL, Reddy KN and Sube Singh. 2006. Development of a Mini Core subset for Enhanced and Diversified utilization of Pigeonpea Germplasm Resources. Crop Science 46:2127-2132.
Upadhyaya HD, Reddy LJ, Gowda CLL, Reddy KN and Sube Singh. 2006. A mini core collection of pigeonpea: An efficient and inexpensible approach to improve a multipurpose crop. Cropscience Society of Agronomy News 51(10):4.
Upadhyaya HD, Reddy LJ, Gowda CLL and Sube Singh. 2006. Identification of diverse groundnut germplasm: Sources of early-maturity in a core collection. Field Crops Research 97:261-267.
Upadhyaya HD, **Shiv Kumar**, Gowda CLL and Sube Singh. 2006. Two major genes for seed size in chickpea (*Cicer arietinum* L.). Euphytica 147:311-315.
Van Oosterom EJ, WELTZIEN E, **Yadav OP**, Bidinger FR. 2006. Grain Yield components of pearl millet under optimum conditions can be used to identify germplasm with adaptation to arid zones. Field Crops Research 96: 407-421.
Varshney RK, Hoisington DA and **Tyagi AK.** 2006. Advances in cereal genomics and applications in crop breeding. Trends in Biotechnology (UK) 24:490-499.
VASANTHI RP, Reddy PV, JAYALAKSHMI V, Sudhakar P, ASALATHA M, Sudhakar Reddy P, Harinatha Naidu P, Muralikrishna T, Venkateswarlu O, John K, Basu MS, Nigam SN, Nageswara Rao RC, and Wright GC. 2006. A high-yielding drought-tolerant groundnut variety Abhaya. International *Arachis* Newsletter 26:15-16.
Velu G, Kulkarni VN, **Muralidharan V**, Rai KN, Longvah T, Sahrawat KL and **Raveendran TS**. 2006. A rapid screening method for grain iron content in pearl millet. International Sorghum and Millets Newsletter 47:158–161.
Verheijen J. 2006. Gender Equality and Mass Media. In: *Etnofoor* [academic anthropological journal] XIX (1): 23-39.
Vilas A Tonapi, Harinath Babu, Ansari NA, Varanavasiappan S, Ravinder Reddy Ch, Navi SS and **Seetharama N**. 2006. Studies on seed coloring in soybean and tomato. International journal of Agricultural sciences II (1):219-224.
Vilas A Tonapi, Harinath Babu, Ansari NA, Varanavasiappan S, Ravinder Reddy Ch, Navi SS and **Seetharama N**. 2006. Studies on seed coloring in Castor, Sunflower and Safflower. Journal of Oil seeds Research 23 (1):72-80
Vilas A Tonapi, Harinath Babu, Ansari NA, Varanavasiappan S, Ravinder Reddy Ch, Navi SS and **Seetharama N**. 2006. Studies on Development of Seed Coloring Standards in Paddy and Maize .Karnataka Journal of agricultural sciences 19(2):278-286.
Vilas A Tonapi, Varanavasiappan S, Navi SS, Ravinder Reddy Ch and Karivatharaju TV. 2006. Effect of environmental factors during seed development and maturation on seed quality in *Sorghum bicolor* (L.) Moench. Plant Archives.6 (2):515-519.
Vilas A Tonapi, Varanavasiappan S, Navi SS, Ravinder Reddy Ch and Karivatharaju TV. 2006. Seed Coloring standards for major Cereals, Pulses and Oil seeds. Plant archives 6(2):477-486.
Wani SP**, Osman M**, Emmanuel D'Silva and SREEDEVI TK. 2006. Improved Livelihoods and Environmental Protection through Biodiesel Plantations in Asia. Asian Biotechnology and Development Review 8(2):11-29.

Conference Proceedings:

Akponikpe P, Bielders C, Gérard B and Karlheinz Michels. 2006. APSIM simulation of millet response to combined application of cattle manure, millet residue and chemical fertilizer in the Sahel. 13th ASA Conference 10-14 September 2006 Perth WA. http://www.regional.org.au/au/asa/2006/concurrent/systems/4588_akponikpep.htm
ARUNA R, Nigam SN, Waliyar F, Upadhyaya HD, Reddy SV, Kanaka Reddy R., Reddy AGS. 2006. Aflatoxin resistance breeding at ICRISAT Center. Page 39 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China
Ashok Kumar A and **Bansal KC**. 2006. Cloning of genes involved in trehalose synthesis from *Escherichia coli*. Pages 1-8 *in* Proceedings of national seminar on “Drought adaptations for sustainable agriculture and livelihood in dry land areas – problems prospects and policies”, February 15-16, 2006. RARS, Palem, ANGRAU. India.
Bendapudi R, Shiferaw B and Wani S. 2006. Livelihood Strategies and Rural Income Inequalities in Selected Semi-arid Indian Watershed Villages. Pages 16 in Poster Paper presented at the 26th IAAE 2006 Conference, Brisbane, Australia: Publisher: International Association of Agricultural Economists.
Blummel M, Parthasarathy Rao P, Pande S and Reddy BVS. 2006. Stover quality of crop-residues: groundnut and sorghum. Pages 95-97 *in* Proceedings of the workshop on Farmers’ Participatory Management of Diseases for Higher Yield and Nutritive Value of Crop Residues of Groundnut, Deccan Plateau, India, ICRISAT. CPE 157.
Chander Rao S, Lava Kumar P, Reddy AS, Swamy Krishna T, Waliyar F, Nigam SN, **LAXMINARASU M** and Sharma KK. 2006. Development and evaluation of transgenic peanut plants against peanut bud necrosis disease (PBND) under greenhouse and field conditions. Pages 101-102 *in* Proceedings of XVI Annual Convention and International Symposium on Management of Vector-Borne Viruses, 7-10 Feb 2006, ICRISAT Center, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
Dar WD, BANTILAN MCS, Anand Babu P, ANUPAMA GV, DEEPTHI H and PADMAJA R. 2006. Asian dryland agriculture: ideas, paradigms and policies. Pages 37 *in* Agricultural and Rural Development in Asia: Ideas, Paradigms, and Policies Three Decades After. Proceedings of an International conference, November 10-11 2005, Makati City, Philippines. College 4031, Los Banos, Laguna, Philippines: The Southeast Asian Regional Center for Graduate Study and Research in Agriculture.
Dar WD, Wani SP and Sahrawat KL. 2006. Converting Desert Areas into Oasis. Pages 3-6 *in* Special Issue on Converting deserts into Oasis on the Occasion of India-Afghanistan Symposium Commemorating, UN International Year of Deserts and Desertification organized by National Academy of Agricultural Sciences (NAAS) held during 19-21 November 2006, New Delhi.
Dileep Kumar Guntuku, ARUNA SAI KUNA, Diwakar Boyanapalle, Balaji Venkataraman. 2006. ITC AQUA CHOUPAL MODEL: An ICT based traceability mechanism for solving Indian shrimp export-oriented problems. Presented at the WCCA2006 (the World Congress on Computers in Agriculture) held at Orlando, Florida, USA, 24-26 July 2006, available at http://asae.frymulti.com/abstract.asp?aid=21926&t=1
Dileep Kumar Guntuku, ARUNA SAI KUNA, **Sreenath Dixit**, and Balaji Venkataraman. 2006. Information and Communication technology (ICT) mediated Open Distance Learning (ODL) methods for Agricultural Extension: A case study from a drought prone area of rural south Asia. Presented at the WCCA2006 (the World Congress on Computers in Agriculture) held at Orlando, Florida, USA, 24-26 July 2006, available at http://asae.frymulti.com/abstract.asp?aid=21871&t=1
Dileepkumar Guntuku and Balaji Venkataraman. 2006. Rapid Customization of Reusable Learning Objects (RLOs): A new paradigm for Content Generation and Localization for Open Distance Agricultural Education and Extension. Presented at the PCF4 (the Fourth Pan Commonwealth Forum on Open learning) held at Ocho Rios, Jamaica, 30 October - 3 November, 2006, available at http://pcf4.dec.uwi.edu/viewabstract.php?id=300.
Hamilton RS, SIE M, Valkoun J, Upadhyaya HD and *MAHALAKSHMI V.* 2006. The need for allele mining: perspectives of the System-wide Genetic Resources Programm (SGRP). Pages 67-68 *in* de Vicente, M.C., Glaszmann, J.C. (eds.) Molecular Markers in Allele Mining. Proceedings of a workshop, 22-26 August, MS Swaminathan Reseach Foundation, Chennai, India. International Plant Genetic Resources Institute, Rome, Italy.

Conference Proceedings:

HOMANN S, *VanRooyen A.*, MOYO T and **NENGOMASHA Z**. 2006. Strengthening livestock market flows and feeding practices for improved livelihoods in southern Zimbabwe. Poster presented at Deutscher Tropentag 2006 Bonn, October 11-13, 2006, Conference on International Agricultural Research for Development. Full paper available at http://www.tropentag.de/2006/abstracts/full/408.pdf
JANILA P and Ashok Kumar A. 2006. Botrytis grey rot disease of castor in Andhra Pradesh and screening for identification of resistance source *in* Proceedings of national seminar on "Drought adaptations for sustainable agriculture and livelihood in dry land areas – problems prospects and policies", 15-16 Feb 2006 at RARS, Palem, ANGRAU. India.
John Pender, **Abdoulaye T**, Ndjeunga J, Gerard B and *Kato Edwards*. 2006. Impacts of Inventory Credit, Input supply shops and fertilizer microdosing in the Drylands of Niger. Paper presented at the 26th Conference of the International Association of Agricultural Economists. Australia.
Jones R, Ntare BR and Kapran I. 2006. Developing viable seed systems for West Africa. Pages 98-100 *in* Strategies and actions for a sustainable agriculture, safe for human health and environmentally friendly. Proceedings of a Ministerial Conference of ECOWAS countries in Biotechnology. 21-24 June 2005, Bamako Mali. Institute d'Economie Rurale, Bamako, Mali
Kajiru GJ, Mrema JP, Mbilinyi BP, Rwehumbiza FB, Hatibu N**, Mowo JG** and **Mahoo HF**. 2006. Assessment of soil fertility status under rainwater harvesting on the Ndala Catchment using local and technical indicators of soil fertility for rice production. Pages 125-133 *in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds). Sokoine University of Agriculture, Tanzania.
Kasele SS, Mlozi MRS, Hatibu N and **Mahoo HF.** 2006. Knowledge sharing and communication tools for dialogue on productivity of water in agriculture in Mkoji sub-catchment, Tanzania. Pages 387-401*in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania.
LUTKAMU M, **SHETTO MC**, **Mahoo HF** and Hatibu N. 2006. Scaling-up and uptake promotion of research findings on NRM in Tanzania. Pages 348-363 *in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania.
Masuki FG, Mutabazi KD, Tumbo SD, Rwehumbiza FB, Mattee AZ and Hatibu N. 2006. Determinants of farm-level adoption of water systems innovations in dryland areas: the case of Makanya watershed in the Pangani River Basin, Tanzania. Pages 330-337 *in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania.
MATI BM. 2006. Appraisal of Policies and institutional frameworks for agricultural water management in Eastern and Southern Africa. Pages 11 *in* SWMnet Proceedings 7, IMAWESA Regional workshop for joint learning, sensitization and planning with country teams, held at Kentmere Country Club, Limuru, Kenya, 16 – 19 May 2006.
MATI BM. 2006. Mainstreaming Improved Management of Agricultural Water in Eastern & Southern Africa into Programme Implementation. Pages 39 *in* SWMnet Proceedings 8, Joint Learning and Planning Workshop for Programme Managers, held at AICAD campus – Juja, Kenya, 11–14th July 2006.
MATI BM. 2006. Identifying stakeholder participation in improved management of agricultural water management in Eastern and Southern Africa. Pages 22 *in* SWMnet Proceedings 6, IMAWESA Expert consultative meeting, held at Izaak Walton Inn, Embu, Kenya, 15–18th January 2006.
MGONJA MA and *Waddington SW*. 2006. Overview of the Challenge Program Water for Food and the Limpopo Basin. Livelihoods in the Limpopo: CGIAR Challenge program on Water and Food project no.1 (CPWFPN1) : Increased Food Security and Income in the Limpopo Basin through integrated crops, soil fertility and water management options and links to markets (Mgonja, MA, Waddington SW, Rollin D and Masenya M, eds.). Pages 4-8 *in* Proceedings of the CPWFPN1 inception workshop 25-27 January 2005, Polokwane, South Africa. PO Box 39063 Nairobi. International Crops Research Institute for Semi Arid Tropics 132pp
MGONJA MA, *Waddington SW, Rollin D* and **Masenya M**. 2006. Livelihoods in the Limpopo: CGIAR Challenge program on Water and Food project no.1 (CPWFPN1) : Increased Food Security and Income in the Limpopo Basin through integrated crops, soil fertility and water management options and links to markets. Pages 132 *in* Proceedings of the CPWFPN1 inception workshop 25-27 January 2005, Polokwane , South Africa. PO Box 39063 Nairobi. International Crops Research Institute for Semi Arid Tropics.
Mkoga Z, Lankford B, Hatibu N, **Mahoo HF**, Rao KPC and **Kasele SS**. 2006. Disparity of attitudes and practices on the concept of productivity of water in agriculture in the Great Ruaha River Sub-Basin, Tanzania Pages 29-39 *in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds.]. Sokoine University of Agriculture, Tanzania.

Conference Proceedings:

Monyo ES, MGONJA MA, **Mkhari JJ, Ramugondo R** and **Chikomba C**. 2006. Models for seed and input supply – Practicability for the Limpopo basin. Livelihoods in the Limpopo: CGIAR Challenge Program on water and Food Project No.1. (CPWF:PN1): Increased Food Security and Income in the Limpopo Basin through integrated crops, soil fertility and water management options and links to markets (Mgonja MA, Waddington S, Rollin D and Masenya M, eds.). Pages 132 *in* Proceedings of the CPWFPN1 Inception Workshop, 25-27 January 2005, Polokwane South Africa. P O Box 776, Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.
Msangi ASK, Senkondo EM, Mutabazi KD, LAZARO EE and Hatibu N. 2006. Transaction costs of rainwater harvesting system management and their effects on access to runoff. Pages 409-419 *in* Proceedings of the East Africa Integrated River Basin Management Conference [Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania.
Mupangwa W, Twomlow S, Hove L and WALKER S. 2006. Effect of minimum tillage and mulching on maize (*Zea mays* L.) yield and water content of clayey and sandy soils. Paper presented at the 7th Waternet-WARFSA-GWP Symposium, Malawi. 30 October-3 November 2006.
Mzirai OB, Tumbo SD, Bwana T, Hatibu N, **Rwehumbiza FB** and Gowing JW. 2006. Evaluation of simulators of missing climate data required for agro-hydrological modelling and water harvesting management planning. Pages 338-347 *in* Proceedings of the East Africa Integrated River Basin Management Conference [Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania.
Narrod C, Roy D, Okello JJ, Avendano B and Thorat A. 2006. Role of Public-private partnerships in ensuring smallholder participation in high valued fruit and vegetable supply chains. A paper presented at the CAPRi Research Workshop on Collective Action and Market Access for Smallholders, Cali, Columbia, 2-5 October, 2006. Available at: http://www.capri.cgiar.org/pdf/CA-Market_Narrod-C.pdf
Ndjeunga J, BANTILAN MSC, Rao KPC and Ntare BR. (eds.). 2006. Impact assessment of Agricultural Technologies in West Africa: Summary. Pages 60 *in* Proceedings of a training workshop on Impact Assessment-Technical notes & Exercises. International Crops Research Institute for the Semi-Arid Tropics.
Okello JJ. 2006. EU food safety standards and impact exports of green bean and fish from Kenya: What role has collective action played. Pre-conference workshop paper, American Agricultural Economics Association meeting, Long Beach, July 22-27, 2006. Available at: http://www.fsn-aaea.org/workshop_06/EU_standards_Kenyan_fish_green_beans.pdf
Okello JJ and Kirimi S. 2006. Developing country farmers' strategic response to developing country food safety standards: The case of Kenyan green bean family farmers. Selected paper, American Agricultural Economics Association meeting, Long Beach, July 22-27, 2006. http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=21808&ftype=.pdf
Okello JJ and Swinton SM. 2006. The effect of developed country pesticide standards on health and pesticide-induced morbidity of Kenya's green bean family farmers. Contributed paper prepared for presentation at the International Association of Agricultural Economists conference, Gold Coast, Australia, August 12-18, 2006. Available at: http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=22499&ftype=.pdf
Pande S, Parthasarathy Rao P, *Blummel M* and **Lakshmi Reddy**. 2006. Effects of plant diseases on crop residues used for peri-urban dairy production on the Deccan Plateau. Pages 145-146 *in* Perspectives on Pests II: Achievements of research under UK department of International development crop protection program 2000-05 (Sweetmore A, Kimins F and Silverside P, eds.). Natural Resource International Limited. UK.
Parthasarathy Rao P and Shravan Kumar V. 2006. Crop-Livestock linkages: A case study of improved groundnut cultivars in the Deccan Plateau. Pages 18-24 *in* proceedings of the workshop on Farmers' Participatory Management of Diseases for Higher Yield and Nutritive Value of Crop Residues of Groundnut, Deccan Plateau, India, ICRISAT. CPE 157
Ramakrishna Reddy Ch, Ravi D, Reddy BVS and *Blümmel M*. 2006. Predictions of digestibility, intake and nitrogen balance of 22 sorghum stover fed to sheep by laboratory traits. Pages 12 *in* proceedings of the XII animal nutrition conference on the technological interventions in animal nutrition for rural prosperity Vol. I, 7-9 Jan 2006, (Bakshi MPS and Wadhwa M, eds.). Animal nutrition society of India, College of veterinary science and animal husbandry, Anand agricultural university, Anand, Gujrat
Rao KPC and **Okwach GE**. 2006. Agricultural Water Management to cope with climatic variability and production uncertainty: How good is it in practice? Pages 19 *in* Book of Abstracts. Water for the Millennium Development Goal on Poverty and Hunger. 2nd Workshop on Agricultural Water Management in Eastern and Southern Africa, Maputo, Mozambique, 18-22 September, 2006.
Rao KPC and **Okwach GE**. 2006. Enhancing productivity of water under variable climate. Pages 2-9 *in* Proceedings of the East Africa Integrated River Basin Managemnet Conference, 7-9th March 2005, Sokoine University of Agriculture, Morogoro, Tanzania.

Conference Proceedings:

Ravi D, Khan A, Reddy BVS and *Blümmel M*. 2006. Sorghum stover as fodder for livestock: variations in intake, digestibility, nitrogen balance and digestible organic matter intake in twenty-two stover fed to sheep. Pages 13 *in* the of the proceedings of the XII animal nutrition conference on the technological interventions in animal nutrition for rural prosperity Vol. I, 7-9 Jan 2006, (Bakshi MPS and Wadhwa M, eds.). Animal nutrition society of India, College of veterinary science and animal husbandary, Anand agricultural university, Anand, Gujrat.
Sagnard F, Gallais A, CHAIR H, DESCLAUX D, **Sekloka E**, Vaksmann M., and WELTZIEN E. 2006. Complémentarité des gestions in situ et ex situ des ressources génétiques dans les programmes de sélection participative. Pages 125-132 *in* Partenaires pour construire des projects de sélection participative. Actes de látelier-recherche (Lancon J, FLOQUET, A and WELTZIEN E eds.). 14-18 mars 2005, Cotonou, Bénin.. http://selection-participative.cirad.fr/
Saqalli M and Gerard B. MOSIM'06 – 3-5 April 2006 – Rabat- Morocco. Full paper. 6th Francophone Conference on Modeling and Simulating "Modélisation, Optimisation et Simulation des Systèmes : Défis et Opportunités". Title: Multi acteurs, multi activités : simulations multi agents pour la détection des changements dans l'Organisation sociale dans les villages de l'ouest nigérien » http://www.isima.fr/mosim06/actes/articles/17-modelisation%20et%20simulation%20d%20ecosystemes/90.pdf
Sharma KK, BHATNAGAR MATHUR P, SAI VISHUN PRIYA K, Anjaiah V, Vadez V, Waliyar F, Lava Kumar P, Nigam SN and Hoisington DH. 2006. Genetic engineering of groundnut for crop improvement. Page 44 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Sharma KK, BHATNAGAR-MATHUR P, **JYOSTNA DEVI M** and Vadez V. 2006. Drought-resistant crops *in* AsianBio 2006, Biotechnology Opportunities for Developing Countries, Third Asian Biotechnology Conference 2006, Manila, Philippines, Nov. 9-10, 2006.
Sharma KK, BHATNAGAR-MATHUR P, **JYOSTNA DEVI M**, VANI G, Vadez V, Verma DPS and YAMAGUCHI-SHINOZAKI K. 2006. Engineering abiotic stress tolerance in chickpea: Expression of P5CSF*129A* and *At DREB1A* genes increase transpiration efficiency under water limiting conditions. In: Sixth Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, University of Delhi, Delhi, Dec. 2-4, 2006.
Sharma KK, Lava Kumar P, Waliyar F, Nigam SN, LAVANYA M, Reddy AS and Swamy Krishna T. 2006. Development and evaluation of transgenic peanuts for induced resistance to the Indian peanut clump virus. Page 37 *in* Proceedings of XVI Annual Convention and International Symposium on Management of Vector-Borne Viruses, 7-10 Feb 2006, ICRISAT Center, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
Sharma KK, SAIVISHNUPRIYA K, Arokiasamy S, Lava Kumar P and Beachy R. 2006. Development of transgenic groundnut for resistance to the tobacco streak virus *in* ICAR-Cornell Program Meeting. Nov. 23, IARI, New Delhi.
Sharma KK, Waliyar F, Lava Kumar P, Reddy SV, Reddy RK, Muthukrishnan S, LAVANYA M, Nigam SN, ARUNA R and Hoisington D. 2006. Development and evaluation of transgenic groundnut expressing the rice *chitinase* gene for resistance to *Aspergillus flavus*. Page 88 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Shiferaw B, BANTILAN MCS and Wani S. 2006. Policy and institutional issues and impacts of integrated watershed management: experiences and lessons from Asia. Pages *in* Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa: Lessons and Experiences from Semi-Arid South Asia (Shiferaw B and Rao KPC, eds.). Proceedings of the International Workshop held at ICRISAT, Nairobi, 6-7 December 2004 Patancheru 502324, India: International Crops Research Institute for the Semi-Arid Tropics.
Shiferaw B, BANTILAN C, Wani SP and SREEDEVI TK. 2006. Collective Action for Integrated Community Watershed Management in Semi-Arid India: Analysis of Multiple Livelihood Impacts and the Drivers of Change. Pages 16 *in* Contributed Paper presented at the 26th IAAE 2006 Conference, Brisbane, Australia: Publisher: International Association of Agricultural Economists. http://agecon.lib.umn.edu/.
Shiferaw B, **Obare** G and Muricho G. 2006. Rural Market Imperfections and the Role of Farmer Organizations in Improving Market Opportunities for Smallholders in Less-favored Areas. Pages 40 *in* Paper presented at the IFPRI/CIAT workshop on Collective Action and Market Access for Smallholders, 2-5 October, 2006, Cali, Colombia.: Publisher: System-wide Program for Collective Action and Property Rights. http://www.capri.cgiar.org/wks_marketrel.asp.

Conference Proceedings:

Shiferaw B, **Obare G** and Muricho G. 2006. Rural Market Imperfections and the Role of Institutions for Collective Action to Improve Markets for the Poor in Sub-Saharan Africa. Pages 19 *in* Paper presented at the Innovation Africa Symposium, 21-23 November, Kampala, Uganda: Publisher: CIAT, Cali, Columbia. http://www.innovationafrica.net/.
Shiferaw B, Silim S and Muricho G. 2006. Economic Benefits from Research Investments in Improving Grain Legumes: Adoption and Impacts of Improved Pigeonpea Technologies in Tanzania. Pages 16 *in* Poster paper presented at the 26th IAAE 2006 Conference, Brisbane: Publisher: Australia: International Association of Agricultural Economists.
Sreenath Dixit, Dileepkumar Guntuku and Balaji Venkataraman. 2006. Rural Knowledge Centers: Partners in Promoting a New ODL Paradigm. Presented at the PCF4 (the Fourth Pan Commonwealth Forum on Open learning) held at Ocho Rios, Jamaica, 30 October - 3 November, 2006, available at http://pcf4.dec.uwi.edu/viewpaper.php?id=326.
Sudarshan Reddy A, Lava Kumar P, Nigam SN and Waliyar F. 2006. Effect of virus titer and date of inoculation on infectivity of Peanut bud necrosis (PBNV), Tobacco Streak virus (TSV), and Indian Peanut clump virus (IPCV) to groundnut. Page 121 *in* Proceedings of XVI Annual Convention and International Symposium on Management of Vector-Borne Viruses, 7-10 Feb 2006, ICRISAT Center, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
Suhas P Wani, SREEDEVI TK and Vamsidhar Reddy TS. 2006. Harnessing Gender Power and Collective Action through Integrated Watershed Management for Minimzing Land Degradation and Sustainable Development**.** Paper presented in the Regional Workshop on Deserts and Desertification, held at NAARM, Rajendranagar, Hyderabad during 29 – 30 December, 2006.
Sylvester Asil Gerard, **Sreenath Dixit**, Diwakar Boyanapalle, **Sahu Ritesh Kumar** and Balaji Venkataraman. 2006. Content Reusability ineLearning : ICRISAT's experiments with LMS. Presented at the third International Conference on eLearning for Knowledge-based Society at Bangkok, Thailand, 2-3 August 2006, available at http://www.ijcim.th.org/v14nSP1/pdf/p12.1-5-fin-38.pdf.
Tom Hash C, Arun Sharma, Nepolean T and Senthilvel S. 2006. Development and application of tools for marker-assisted breeding in pearl millet *in* Plant & Animal Genomes XIV Conference, January 14-18, 2006, San Diego, CA
Tumbo SD, Mpulila T, Mzirai OB, Mahoo HF, Rwehumbiza FB, Semoka JMR and Hatibu N. 2006. Transaction costs of rainwater harvesting system management and their effects on access to runoff. Pages 409-419 *in* Proceedings of the East Africa Integrated River Basin Management Conference (Lankford BA and Mahoo HF, eds.). Sokoine University of Agriculture, Tanzania**.**
Twomlow S and Rao KPC. 2006. Research on integrated soil and water management in semi-arid eastern and southern Africa: Past Experiences, current activities and future thrusts. Integrated management of watersheds for agricultural diversification and sustainable livelihoods in eastern and central Africa: Lessons and experiences from semi-arid South Asia (Shiferaw B and Rao KPC, eds). Proceedings of the International Workshop held at ICRISAT, Nairobi, 6-7 December, 2004. Patancheru 502324, Andrha Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. 53-58. ISBN 92-9066-487-8. Order Code CPE158.
Twomlow S, Rohrbach D, Hove L, Mupangwa W, Moyo M, MASHINGADAIZE N and Chiroro C. 2006. Boost from Basins. Proceedings of 17th Triennial Conference of the International Soil and Tillage Research Organisation, 'Sustainability – its impact on soil management and the environment. 28 August to 3 September, Christian-Albrechts-Universität zu Kiel, Germany. CD-ROM ISBN 3-9811134-0-3.
Upadhyaya HD, *Baum M, BUHARIWALLA HK., Udupa SM, FURMAN BJ,* Dwivedi SL, Hoisington DH, Gaur PM., Chandra S, Gowda CLL, *Crouch JH* and *Valkoun J*. 2006. Mining Chickpea Composite Collection for Allelic Variation. Page 25 *in* Molecular Markers in Allele Mining (de Vicente MC and Glaszmann JC, eds.). Proceedings of a workshop, 22-26 August, MS Swaminathan Reseach Foundation, Chennai, India. International Plant Genetic Resources Institute, Rome, Italy.
Upadhyaya HD, **BHATTACHARJEE R,** Hoisington DA, Chandra S, Singh S, Bertioli D, Moretzsohn MC, Leal-Bertioli S, Guimaraes P and Valls JFM. 2006. Genotyping groundnut (*Arachis hypogaea* L.) Composite collection. Paper presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Gowda CLL, **BHATTACHARJEE R**, Anisetti NM and Singh L. 2006. Pigeonpea Germplasm Collection- A global perspective. Paper presented in the joint ICRISAT-Global Crop Diversity Trust Consultation Meeting for "Developing a strategy for the global conservation of pigeonpea genetic resources" 23-24 August 2006. ICRISAT, Patancheru, India.

Conference Proceedings:

Upadhyaya HD, Pundir RPS, Sube Singh and Gowda CLL. 2006. Procedures and protocols to maintain purity and viability of peanut (groundnut) germplasm. Pages 73-88 *in* Improving yield and economic viability of peanut production in Papua New Guinea and Australia (Rachaputi RCN, Wright G, Kuniata L and Ramakrishna A, eds.). Proceedings of a workshop, 18-19 October 2005. Lae, Papua New Guinea, Canberra, ACIAR Proceedings No. 122, 124 pp.
Vadez V, Hash CT, Rizvi SMH, Bidinger FR, **Banttee K**, Sharma KK, DEVI MJ, BHATNAGAR-MATHUR P, Kashiwagi J, Krishnamurthy L, Hoisington D, Varshney RK, Gaur PM, Nigam SN, ARUNA R and Upadhyaya HD. 2006. What is the scope for molecular breeding and genetic engineering to improve crops' drought tolerance? Proceeding of the 4th Biovision Conference, Alexandria 26-29 April 2006.
Vadez V, Krishnamurthy L, Gaur PM, Upadhyaya HD, Hoisington DA, Varshney RK, Turner NC and Siddique KMH. 2006. Tapping the large genetic variability for salinity tolerance in chickpea. Proceeding of the Australian Society of Agronomy meeting (10-14 Sept 2006). http://www.regional.org.au/au/asa/2006/concurrent/environment/4561_vadez.htm
Valluru R, RIZVI R, Hash CT and Vadez V. 2006. Efficient Microdosing of Phosphorus to Pearl millet Hybrids (*Pennisetum americanum* L.) for Improved Seedling Establishment under Nutrient-Stressed Environments. Chapter 22, Pages 1-13 *in* Proceeding of the National conference on the role of plant physiology and biotechnology in biodiversity conservation and agriculture productivity, Jaipur 24-26 Feb 06, (Kumar A and Shekhawat NS, eds.). IK International Publishing House, New Delhi.
Varshney RK, Hoisington DA, Upadhyaya HD, Vadez V, Gaur PM, ARUNA R, Kashiwagi J, **BHATTACHARJEE R**, Nigam SN, JAYASHREE B, Saxena KB and Chandra S. 2006. Genomics approaches to enhance molecular breeding strategies in legume crops of the semi-arid tropics. BARC DAE-BRNS Golden Jubilee Celebration, Life Science Symposium (LSS), Bhabha Atomic Research Centre (BARC), December 18-20, 2006.
Varshney RK and Hoisington DA. 2006. Functional molecular markers in plant breeding. Pages 65-70 *in* Proceedings of the training workshop on "Molecular Markers and Transgenics for Precision in Rice Breeding, March 20-29, 2006. ICAR: Directorate of Rice Research (DRR), Rajendranagar,Hyderabad.
Varshney RK, Hoisington D, Upadhyaya HD, Vadez V, Gaur PM, Dwivedi S, ARUNA R, Kashiwagi J, BHATTACHARJEE R, Nigam SN, Balaji J and Chandra S. 2006. Improvement of water-stress tolerance in chickpea and peanut: Application of genomic and physiological approaches. Page 245-246 *in* Bibliotheca Fragmenta Agronomica. Proceedings of the IX ESA Congress, Part I Vol 11, 4-7 Sep 2006, Warszawa, Poland. European Society for Agronomy/Polish Society for Agronomy.
Waliyar F, Craufurd P, PADMAJA KV, Reddy RK, Reddy SV, Nigam SN and Lava Kumar P. 2006. Effect of soil application of lime, crop residue and biocontrol agents on pre-harvest *Aspergillus flavus* infection and aflatoxin contamination in groundnut. Page 80 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Wani SP, **Anil Shah C** and SREEDEVI TK 2006. Dialogue on Improving Watershed Policies, Practices and Knowledge to Impact People and Ecosystems. Pages 32 *in* Proceedings of the Dialogue, 24-25 November 2005, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andrha Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.
Wani SP, **Ramakrishna YS**, SREEDEVI TK, **Long TD**, **Thawilkal Wangkahart**, Shiferaw B, Pathak P and Kesava Rao AVR. 2006. Issues, Concepts, Approaches and Practices in the Integrated Watershed Management: Experience and lessons from Asia in Integrated Management of Watershed for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa: Lessons and Experieces from Semi-Arid South Asia. Pages 17–36 *in* Proceedings of the International Workshop held 6 – 7 December 2004 at Nairobi, Kenya.
Wani SP, SREEDEVI TK, **Ramakrishna YS**, Piara Singh and Pathak P. 2006. Improved Livelihoods in Watersheds through Consortium Approach: Reflections and Learnings. Pages 33-66 *in* Proceedings of National Workshop on development: Future Challenges held on 10 February 2006 at New Delhi.
Wani SP, SREEDEVI TK, Vamsidhar Reddy TS and Pathak P. 2006. Conservation and enhancing of natural resources for improved livelihoods through integrated watershed management. Pages 123-131 *in* Proceedings of Regional Conference, "Natural Resource Conservation, Use and Sustainability in Drylands" held at Bhuj organized by GUIUDE and Abhiyan, Bhuj, Gujarat, India.18-20 December 2006.
WELTZIEN E, CHRISTINCK A, **Ag Hamada M, Toure A** and Rattunde HFW. 2006. Améliorer l'accès des paysans maliens aux variétés des sorgho grâce a la sélection participative. Pages 49-60 *in* Partenaires pour construire des projects de sélection participative. Actes de látelier-recherche (Lancon J, **FLOQUET A** and WELTZIEN E, eds.). 14-18 mars 2005, Cotonou, Bénin. Cirad, Inrab, Coopération francaise,

Conference Proceedings:

Montpellier, France.
Weltzien E, Rattunde HFW, Clerget B, Siart S, Toure A and Sagnard F. 2006. Sorghum diversity and adaptation to drought in West-Africa. *in* Enahancing the use of crop genetic diversity to manage abiotic stress in agricultural production systems (Jarvis D, Mar I, and Sears L, eds.). Proceedings of a workshop, 23-27 May 205, Budapest, Hungary. International Plant Genetic Resources Institute, Rome, Italy.
Zaid Abdul-Hadi, Siham Asaad, Bassam Bayaa, Mohamed Dahab, Soliman Edris, Said El-Azhary, Khaled El-Bahnasy, Abdel Rahaman El-sayed, Mohamed El-Zemaity, Stefania Gando, Habib Ketata, **SAFAA KUMARI**, *Rajendra Malhotra, Moussa Mosaad,* Suresh Pande, *Ahmed Rafea, Ahmed Ragab,* Ranga Rao GV, *Ahmed aid, Ashraf Shata* and *Amor Yehyaoui*. 2006. Rapid Generation of Plant Protection Expert Systems. Pages 282-287 *in Proceedings* of the 4th World Congress on Computers in Agriculture and Natural Resources (Fedro Zazueta, Jiannong Xin, Seishi Ninomiya and Gerhard Schiefer, eds.). Published by American Society of Agricultural and Biological Engineers, 2950 Niles Road, St. Joseph, Michigan 49085-9659 USA.

Book Chapters:

Azhaguvel P, Vidya Saraswathi D, Sharma A and Varshney RK. 2006. Methodological advancement in Molecular markers to delimit the gene(s) for crop improvement. Pages 460-469 *in* Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues (Teixera da Silva J, ed.), Global Science Books, London, UK.
Blummel M, Parthsarathy Rao, Pande S and Reddy BVS. 2006. Stover quality of crop residues: Groundnut and Pages 95-97 *in* Farmers' participatory management of diseases for higher yield and nutritive value of crop resi groundnut, Deccan Plateau, India (Pande S, Srinivas B, Parthasarathy Rao P, Narayana Rao J and Lakshmi Re Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Pata Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.168 pp. ISBN 92-906
CLARKE H, Shan F, MALLIKARJUNA N, LULSDORF M, WILSON JG and Siddique KHM. 2006. Unlock treasure chest for chickpea improvement: Utilisation of annual wild *Cicer* in wide crosses. Pages 286-294 *in* Australasian Plant Breeding Conference (Mercer C, ed.). Christchurch, New Zealand.
Clerget B and Chantereau J. 2006. Improving sorghum crops for farmers in West and Central Africa. *In* Franc CGIAR: Delivering scientific results for agricultural development. CGIAR Secretariat, Washington DC.
Diatta S and Sahrawat KL. 2006. Iron toxicity of rice in West Africa: Screening tolerant varieties and the role K, and Zn. Pages 75-81 *in* Iron Toxicity in Rice-Based Systems in West Africa (Audebert A, Narteh LT, Kiep Millar D and Beks B, eds.). Africa Rice Center (WARDA), Cotonou, Benin, West Africa.
English P, Jaffee S and Okello JJ. 2006. Exporting out of Africa: The Kenya Horticulture Success Story. Page 145, Chapter 5 *in* Attacking Africa's Poverty: Experiences from the Ground (Liebenthal RB and Fox ML, ed Bank, Washington DC.
Gahlawat SK, CHHABRA B, **Jain KL, Gupta RK,** Dhillon M and **Sihag RC.** 2006. A review on the honey: A By-product of bees (Insecta: Hymenoptera). Nutritional and medicinal aspects. Pages 102-126 *in* Perspective in Animal Ecology and Reproduction Vol. III Eds. V.K. Gupta and Anil K. Verma. Daya publishing house, New Delhi.
Gaur PM, Saxena KB, Nigam SN, Reddy BVS, Rai KN, Gowda, CLL and Upadhyaya HD. 2006. Plant breeding research at ICRISAT. Pages 455-458 *in* Principles of Plant Genetics and Breeding (Acquaah G, author). Blackwell Publishing, USA/Canada/Australia.
Gowda CLL and Rai KN. 2006. Evolution of hybrid parents research. Pages 1-10 *in* Hybrid Parents Research at ICRISAT (Gowda CLL, Rai KN, Reddy Belum VS and Saxena KB, eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 216 pp.
Holden S, Shiferaw B and *Pender J.* 2006. Policies for Poverty Reduction, Sustainable Land Management and Food Security: A Bio-economic Model with Market Imperfections *in* Strategies for sustainable land management in the East African highlands (PenderJ, Place F and Ehui S, eds.). Washington, DC: IFPRI Press.
Jauhar PP, Rai KN, OZIAS-AKINS P, Chen Z and Hanna WW. 2006. Genetic improvement of pearl millet for grain and forage production: cytogenetic manipulation and heterosis breeding. Pages 281–307 *in* Genetic resources, chromosome engineering, and crop improvement-cereals (Singh RJ and Jauhar PP, eds.). CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742, USA.

Book Chapters:

Jones RB, Freeman HA, **Lo Monaco G,** Walls S and Londner SI. 2006. Improving the access of small farmers in Africa to global markets through the development of quality standards for pigeonpeas in Agricultural Standards. Pages 177-191 *in* The Shape of the Global Food and Fiber System (Springer J Bingen and Busch L, eds.).
Khairwal IS and Rai KN. 2006. Status of research and development of pearl millet in India. Pages 63–82 *in* Strategies for Millets Development and Utilization. (Seetharama N and Tonapi VA, eds.). National Research Centre for Sorghum, Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India.
Koebner RMD and Varshney RK. 2006. The development and application of genomic models for large crop plant genomes. Pages 1-10 *in* Model Plants, Crop Improvement (Varshney RJ and Koebner RMD, eds.). CRC Press, Florida, USA,.
Kumar PL, Jones AT and Waliyar F. 2006. Virus diseases of pigeonpea, with particular reference to sterility mosaic and yellow mosaic diseases. Pages 235-258, Volume 3 *in* Characterization, Diagnosis and Management of Plant Viruses. Vegetable and Pulse Crops (Rao GP, Kumar PL and Penna RJH, eds.). Studium Press LLC, Texas, USA. pp235-258.
Kumar PL, *KUMAR, SG* and Waliyar F. 2006. Virus diseases of chickpea. Pages 213-234, Volume 3 *in* Characterization, Diagnosis and Management of Plant Viruses: Vegetable and Pulse Crops (Rao GP, Kumar PL and Penna RJH, eds.). Studium Press LLC, Texas, USA.
MATI BM. 2006. Capacity Development strategies: lessons from Promoting Farmer Innovation (PFI) in East Africa. Pages 37-48 *in* Design and Implementation of Capacity Development Strategies. IPTRID, FAO, Rome.
Msangi S, RINGLER C and Rosegrant MW. 2006. The future of agricultural and water: market and policy-based strategies for sustainability: What can the developing world learn from North America? Pages 57-78 *in* Water and Agriculture: Sustainability, markets and policies. OECD, Paris.
Narteh LT and Sahrawat KL. 2006. Evaluating the relationship between selected Fe extraction methods and some rice growth parameters. Pages 149-168 *in* Iron Toxicity in Rice-Based Systems in West Africa (Audebert A, Narteh LT, Kiepe P, Millar D and Beks B, eds.). Africa Rice Center (WARDA), Cotonou, Benin, West Africa.
Ntare BR. 2006. *ARACHIS HYPOGAEA L*. Pages 21-29 *in* Ressources végétale de l'Afrique tropicale 1. Céréales et legumes secs: Plant Resources of Tropical Africa1 (Brink M and Belay G, eds.). Cereals and pulses. 2006, Foundation PROTA, Wageningen, Pay-Bas. Backhuys Publishers, Leiden, Pays-Bas. CTA, Wageningen, Pays bas. 328 pp.
Pande S. 2006. Plant Pathology in India vis-à-vis International Cooperation. Pages 377-400 *in* One Hundred Years of Plant Pathology in India an Overview. Indian Society of Mycology and Plant Pathology, Maharana Pratap University of Agriculture & Technology, Udaipur 311 001, Rajasthan, India.
Pande S, Krishna Kishore G and Narayana Rao J. 2006. Status and Prospects of Integrated Pest Management Strategies in Selected Crops: Groundnut. Pages 280-296, Volume 2 *in* Integrated Pest Management, Principles and Applications. Applications by America Singh, Sharma OP and Garg DK. CBS Publishers & Distributors, 4596/1-A, 11Darya Ganj, New Delhi 110 002.
Pande S, Krishna Kishore G and Narayana Rao J. 2006. Integrated management of groundnut fungal diseases. Pages 37-44 *in* Farmers' participatory management of diseases for higher yield and nutritive value of crop residues of groundnut, Deccan Plateau, India (Pande S, Srinivas B, Parthasarathy Rao P, Narayana Rao J and Lakshmi Reddy, eds.) Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.168 pp. ISBN 92-9066-485-1.
Pande S, Narayana Rao J, **Lakshmi Reddy P** and Krishna Kishore G. 2006. Influence of IDM on groundnut yields in the Deccan Plateau, Andhra Pradesh. Pages 57-66 *in* Farmers' participatory management of diseases for higher yield and nutritive value of crop residues of groundnut, Deccan Plateau, India (Pande S, Srinivas B, Parthasarathy Rao P, Narayana Rao J and Lakshmi Reddy, eds.). Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 168 pp. ISBN 92-9066-485-1.
Pande S, Rao PP, Waliyar F, *Blummel M* and **Lakshmi Reddy**. 2006. Effects of plant diseases on crop residues used for peri-urban dairy production on the Deccan Plateau. Pages 145-146 *in* Perspectives on Pests II- Achievements of research 2000-05 (Anne Sweetmore, Frances Kimmins and Penny Silverside, eds.). UK: Department for International Development Crop Protection Programme.
Pande S, Yantai Gan, Pathak M and **Yadav S**. 2006. Integrated Crop Production and Management Technology of Chickpea. Pages 269-285 *in* Chickpea Breeding and Management (Yadav S, Bob Reddan, Weidong Chan and Balram Sharma, eds.). CAB International, UK.

Book Chapters:

Prabhakar Pathak. 2006. Sustainable management of land and water resources for achieving food security in the rainfed areas. Pages 319-331 *in* Land Use Diversification for Sustainable Rainfed Agriculture (Sharma KD and Soni R, eds.). Atlantic Publishers and Distributors, New Delhi, India.
Rai KN. 2006. Heterosis breeding in pearl millet. Pages 102–113 *in* Heterosis in Crop Plants (Kaloo G, Rai M, Singh M and Kumar S, eds.). Researchco Book Center, New Delhi, India. 390 pp.
Rai KN, Kulkarni VN, Thakur RP, HAUSSMANN BIG and MGONJA MA. 2006. Pearl millet hybrid parents research: approaches and achievements. Pages 11-74 *in* Hybrid Parents Research at ICRISAT (Gowda CLL, Rai KN, Reddy BVS and Saxena KB, eds.). International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India. 216 pp. ISBN 92-9066-489-4.
Ramakrishna YS, **Rao GGSN**, Kesava Rao AVR, **Vijaya Kumar P**. 2006. Agroclimatic Characterization: Need, Concept and Methodology. Pages 73-92 *in* Land Use Diversification for Sustainable Rainfed Agriculture (Sharma KD and Soni B, eds.). New Delhi, India: Atlantic Publishers and Distributors.
Ramana Reddy Y, **Sivaiah K**, **Janardhan Reddy**, Pande S and *Blummel M*. 2006. Effect of diseased groundnut and sorghum crop residues on nutrient utilization in cattle. Pages 89-94 *in* Farmers' participatory management of diseases for higher yield and nutritive value of crop residues of groundnut, Deccan Plateau, India (Pande S, Srinivas B, Parthasarathy Rao P, Narayana Rao J and Lakshmi Reddy, eds.). Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 168 pp. ISBN 92-9066-485-1.
Ravinder Reddy Ch, **Tonapi VA,** *Prasad V L* and *Peter Bezkorowajny*. 2006. Innovative seed systems and seed delivery models for food-feed-fodder security in semi-arid tropics of Andhra Pradesh. Pages 57-72 *in* Prosperity through quality seed. Organized by Indian Society of Seed Technology, New Delhi and Acharya NG Ranga Agricultural University, Hyderabad, 24-26 February, 2006.
Reddy BVS, **Ramesh S**, Gowda CLL and **Seetharama N**. 2006. Global Sorghum Improvement Research and its Relevance to India. 2006. Pages 93-117 *in* Strategies for Millets Development and Utilization (Seetharama N and Tonapi VA, eds). Society for Millets Research, 11-127, National Research Center for Sorghum, Rajendranagar, Hyderabad-500 030, Andhra Pradesh, India. 232pp.
Reddy BVS, **Ramesh S** and SANJANA REDDY P. 2006. Approaches to Exploit Heterosis in Sorghum. Pages 78-101 *in* Heterosis in Crop Plants (Kallo G, Rai M, Singh M and Kumar S, eds.). Researchco Book Centre, New Delhi, India.
Reddy BVS, **Ramesh S** and SANJANA REDDY P. 2006. Genetic Resources, Cytogenetic manipulation and Sorghum Improvement. Pages 309-363 *in* Genetic Resources, Chromosome Engineering, and Crop Improvement-Cereals (Singh RJ and Jauhar PP, eds.). CRC Press, LLC, Boca Raton, USA.
Reddy BVS, **Ramesh S**, Sharma HC, Thakur RP, Fred Rattunde, MARY MGONJA, Hash CT and Vadez V. 2006. Sorghum Hybrid Parents Research at ICRISAT–Strategies and Impacts. Pages 75-165 *in* Hybrid Parents Research at ICRISAT (Gowda CLL, Rai KN, Reddy BVS and Saxena KB, eds.), Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 216pp. ISBN 92-9066-489-4.
Reddy V Ratna**, Reddy M Gopinath, Ravi Kumar VM** and **Reddy M Srinivas**. 2006. Fission or Fusion: An Assessment of Decentralisation of Forest Management in Andhra Pradesh. Pages 73-91 in Sustainable Development and Indian Economy: Issues and Challenges (Sailabala Debi and Annigiri VB, eds.). Serial Publications, New Delhi.
Rupela OP, Gowda CLL, Wani SP and **HAMEEDA BEE**. 2006. Evaluation of crop production systems based on locally available biological inputs. Pages 501-515 *in* Biological Approaches to Sustainable Soil Systems (Uphoff N et al, eds.), CRC Taylor & Francis, Boca Raton, Florida, USA.
Sahrawat KL. 2006. Plant nutrients: sufficiency and requirements. Pages 1306-1310 *in* Encyclopedia of Soil Science (Lal R, ed.). Second Edition. Taylor and Francis, Philadelphia, PA, USA.
Sahrawat KL, **Murugappan V** and **Raju AP**. 2006. Soil and water quality issues vis-à-vis agricultural management practices in Deccan plateau. Pages 173-183 *in* International Conference on Soil, Water and Environmental Quality—Issues and Strategies—January 28-February 1, 2005, New Delhi: Proceedings. Indian Society of Soil Science, Indian Agricultural Research Institute, New Delhi, India.
Saxena KB and Kumar RV. 2006. Hybrid Pigeonpea: Research and Development *in* Hybrid Parents Research at ICRISAT (Gowda CLL, Rai KN, Reddy Belum VS and Saxena KB, eds.) International Crops Research Institute for the Semi-Arid Tropics. 216 pp.
Sharma HC. 2006. Strategies for *Helicoverpa* management in different agro-ecosystems. Pages 165-177 *in* Emerging Trends in Economic Entomology (Chillar BS, Saini RK and Lal R, eds.). Hisar, Haryana, India: Centre for Advanced Studies, Department of Entomology, CCS Haryana Agricultural University.

Book Chapters:

Sharma KK and **BHATNAGAR-MATHUR P.** 2006. Peanut (*Arachis hypogaea* L.). Pages 347-358, Volume 343 *in* Methods in Molecular Biology (Kan Wang, ed.). *Agrobacterium* Protocols, 2/e, volume 1, Humana Press Inc., Totowa, USA.
Sharma KK, **BHATNAGAR-MATHUR P** and **Jayanand B.** 2006. Chickpea (*Cicer arietinum* L.). Pages 313-323, Volume 343 *in* Methods in Molecular Biology (Kan Wang, ed.). *Agrobacterium* Protocols, 2/e, volume 1, Humana Press Inc., Totowa, USA.
Sharma KK, **SREELATHA G** and **DAYAL S.** 2006. Pigeonpea [*Cajanus cajan* L. (Millsp.)]. Pages 359-367, Volume 343 *in* Methods in Molecular Biology (Kan Wang, ed.). *Agrobacterium* Protocols, 2/e, volume 1, Humana Press Inc., Totowa, USA.
SREEDEVI TK. 2006. Capitalizing on Powerguda's Capitals to Improve Livelihoods. Pages 19-29 *in* Proceedings of Book titled "Learning Participation in Action. Field Research Experiences in South Asia" (Campilan D, Bertuso A, Ariyabandu R and Sister L, eds.). CIP-Upward, Los Banos. Laguna. Philippines.
Sreenivasaprasad S, **Takan JP**, MGONJA MA, Manyasa EO, Kaloki P, **Wanyera NM, Okwadi J,** Muthumeenakshi S, Brown AE and LENNE JM. 2006. Enhancing finger millet production and utilization in East Africa through improved blast management and stakeholder connectivity. Pages 11-22 *in* Aspects of Applied Biology 75, Pathways Out Of Poverty (Harris D, Richards JI, Riverside P, Ward AF and Witcombe JR, eds.). Association of Applied Biologists, UK.
Sreenivasulu P, Subba Reddy ChV, Ramesh B and Kumar PL. 2006. Important virus diseases of groundnut. Pages 47-98, Volume 1 *in* Characterization, Diagnosis and Management of Plant Viruses: Industrial Crops (Rao GP, Paul Khurana Sm and Lenardon SL, eds.). Studium Press LLC, Texas, USA.
Shiferaw B, BANTILAN B and Wani S. 2006. Policy and institutional issues and impacts of integrated watershed management: experiences and lessons from Asia *in* Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa: Lessons and Experiences from Semi-Arid South Asia (Shiferaw B and Rao KPC, eds.). ICRISAT, Patancheru 502324, India.
Shiferaw B, Rao B and Hatibu N. 2006 Conclusions and future directions *in* Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa: Lessons and Experiences from Semi-Arid South Asia (Shiferaw B and Rao KPC, eds.). ICRISAT, Patancheru 502324, India.
Srinivas B, Pande S and Narayana Rao J. 2006. Genesis of participatory IDM technology in ICGV 91114, a dual purpose, short duration, high yielding groundnut cultivar in Anantapur, India. Pages 12-17 *in* Farmers' participatory management of diseases for higher yield and nutritive value of crop residues of groundnut, Deccan Plateau, India (Pande S, Srinivas B, Parthasarathy Rao P, Narayana Rao J and Lakshmi Reddy, eds.). Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 168 pp. ISBN 92-9066-485-1.
Srinivasarao Ch. 2006. Role of optimum plant nutrition in drought management. Pages 173-180 *in* Drought Management. Allied Publishers, New Delhi.
Stevenson PC, Grazywacz D, Pande S, MoAC Nepal and **Neupane RK**. 2006. Promoting the adoption of improved ICM technologies in chickpea by poor farmers in Nepal. Pages 152-154 *in* Perspectives on Pests II-Achievements of research 2000-05 (Anne Sweetmore, Frances Kimmins and Penny Silverside, eds.) UK: Department for International Development Crop Protection Programme.
Stevenson PC, Grazywacz D, Pande S, Rao JN, **Neupane RK**, **Chaudhary** and **Bourai VA**. 2006. Policy and Strategy for improved chickpea ICM in Nepal and south Asia. Pages 155-156 *in* Perspectives on Pests II-Achievements of research 2000-05 (Anne Sweetmore, Frances Kimmins and Penny Silverside, eds.). UK: Department for International Development Crop Protection Programme.
Subbian P and MarimuthuS. 2006. Problems and prospects of dryland agriculture in India. Pages 167-187, Volume1 *in* Advances in seed science and technology. Recent trends in seed technology and management, Agrobios (India), Agrohouse, Behind Nasrani Cinema, Chopasani road, Jodhpur-342002. ISBN No. 81-7754-258-3.
Twomlow SJ, **Steyn T** and **du Preez CC**. 2006. Dryland farming in Southern Africa. Pages 769-836, Chapter 19 *in* Dryland Agriculture (Pearson GA, Unger PW and Payne WE, eds.). Agronomy Monograph No.23 Second Edition. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin.

Book Chapters:

Wani SP**,** MEERA REDDY, SREEDEVI TK and **Raju Damle**. (eds.). 2006. Corporate Science and Technology Institutions – Partnerships for Inclusive and Sustainable Development and Economic Growth *in* Proceedings of the CII-ICRISAT Workshop, 27 February 2006. ICRISAT, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp.
Wani SP**,** Piara Singh, PADMAJA KV, **Dwivedi RS** and SREEDEVI TK. 2006. Assessing Impact of Integrated Natural Resource Management Technologies in Watersheds. Pages 38-58 in Impact Assessment of Watershed Development - Issues, Methods and Experiences (Palanisami K and Suresh Kumar D, eds.).
WELTZIEN E, CHRISTINCK A, Toure A, Rattunde HFW, Diarra M, Sangare A and Coulibaly M. 2006. Pages 61-72 *in* Enhancing farmers' access to sorghum varieties through scaling up participatory plant breeding in Mali, West-Africa, Bringing Farmers back to Breeding (ALMEKINDERS C and Hardon J, eds.). Experiences with participatory Plant Breeding and Challenges for Institutionalization. Agromisa Special, Agromisa, Wageningen.

Books and Journal Volumes:

Ashok Kumar A and **Ram Prakash T.** (eds.). 2006. Proceedings of the national seminar on "Drought adaptations for sustainable agriculture and livelihoods in rural areas: problems, prospects and policies". February 15-16, 2006. RARS, Palem, Andhra Pradesh, India
Ganeswara Rao A, Rahman SJ, Vasudeva Rao V, Surendra Babu P and Ashok Kumar A. 2006. Strides in 25 years of research in southern Telangana zone of Andhra Pradesh. RARS, Palem, India.
Gowda CLL, Rai KN, Reddy Belum VS and Saxena KB. (eds.) 2006. Hybrid parents research at ICRISAT. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 216 pp.
Kumar PL, **Muralidharan K,** SUGANYA S and Waliyar F. (eds). 2006. Management of Vector-Borne Viruses. ICRISAT and Indian Virological Society. 123pp.
<u>Lancon J,</u> **FLOQUET A** and WELTZIEN E. (eds). 2006. Partenaires pour construire des projects de sélection participative. Actes de látelier-recherche, 14-18 mars 2005, Cotonou, Bénin. 207 pp. Cirad, Inrab, Coopération Francaise, Montpellier, France.
Ndjeunga J, BANTILAN MCS, Rao KPC and Ntare BR. (eds). 2006. Impact Assessment of Agricultural Technologies in West Africa: Training Workshop on Impact Assessment 12-16 July 2004, West Africa, Bamako- Mali. BP 320, Bamako, Mali: International Crops Research Institute for the Semi-Arid Tropics. 60 pp.
Ndjeunga J, Ntare BR, Waliyar F and <u>Ramouch M.</u>. (eds). 2006. Groundnut seed systems in West Africa. CFC Technical Paper No. 40. PO Box 74656, 1070 BR Amsterdam, The Netherlands: Common Fund for Commodities, and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 232 pp (French and English version).
Pande S, **Srinivasa Rao B** and Parthasarathy Rao P. (eds.). 2006. Proceedings of the workshop on Farmers' Participatory Management of Diseases for Higher Yield and Nutritive Value of Crop Residues of Groundnut in Deccan Plateau of India, 3-4 January 2005, ICRISAT, CPE 157. 168 pp.
Pande S, **Srinivas B**, Parthasarathy Rao P, Narayana Rao J and **Lakshmi Reddy.** (eds). 2006. Farmers' participatory management of diseases for higher yield and nutritive value of crop residues of groundnut, Deccan Plateau, India. Proceedings of workshop, 3-4 January 2005, ARS, ANGRAU, Rekulakunta, Anantapur, Andhra Pradesh. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.168 pp.
Peden D, Freeman A, Astatke A, NORTENBAERT A, Ayalneh W, Baltenweck A, El Wakeel A, Fadlalla B, Elzaki R, Faki H, MATI B, Sonder K and Workalemahu A. 2006. Investment Options for Integrated water-Livestock-crop production in sub-Saharan Africa. ILRI and IWMI, Addis Ababa, Ethiopia. 52 pp.
Rao GP, Kumar PL and <u>Pena RJH</u>. (eds). 2006. Characterization, Diagnosis and Management of Plant Viruses, Volume 3: Vegetable and Pulse Crops. Studium Press LLS, Texas, USA. ISBN# 1-933699-33-7.
Reddy Belum VS, Sharma HC, Thakur RP and Ramesh S. 2006. Characterization of ICRISAT-bred sorghum hybrid parents. International Sorghum and Millets Newsletter 47 (special Issue) (Thakur RP ed.). 131 pp.
Reddy V Ratna and **Mahendra Dev S**. 2006. Managing Water Resources: Policies, Institutions and Technologies. **(**eds.) Oxford University Press, New Delhi.
Saxena KB. 2006. Seed production systems in pigeonpea. Patancheru, 502 324, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. 76 pp. ISBN 92-9066-490-8.

Books and Journal Volumes:

Shiferaw B and Rao KPC. (eds). 2006. Integrated Management of Watersheds for Agricultural Diversification and Sustainable Livelihoods in Eastern and Central Africa: Lessons and Experiences from Semi-Arid South Asia. Proceedings of the International Workshop held at ICRISAT, Nairobi, 6-7 December, 2004. Patancheru 502324, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Pages 53-58. ISBN 92-9066-487-8. Order Code CPE 158.
Tabo R, Koala S, van Rooyen A, Ayantunde A, Bationo A and **Sessay M.** (eds.). 2006. Combating Desertification and increasing Biodiversity: Best bet technologies adopted in DMP member countries. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. 78pp
Thakur RP and Dahlberg JA. (eds). 2006. International Sorghum and Millets Newsletter, Vol. 47. Sorghum Improvement Conference of North America Lubbock, TX 79403, USA and International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, India. 182 pp.
Varshney RK and Koebner RMD. 2006. Model Plants Crop Improvement, CRC Press Inc, Florida, USA. 336 pp.
Wani SP, MULA ROSANA P, SREEDEVI TK and Raju KV. (eds). 2006. Comprehensive Assessment of Watershed Programs in India. Proceedings of the Inception Workshop, 6-7 June 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 100 pp. ISBN 978-92-9066-497-0.

Monographs:

BANTILAN MCS, Anand Babu P, ANUPAMA GV, DEEPTHI H and PADMAJA R. 2006. Dynamics, challenges and priorities of dryland agriculture in Asia and Sub-Saharan Africa. Research Bulletin. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 32pp.
Barnabas N Mitaru. 2006. Sorghum and Millet Research for Development in Eastern and Central Africa 2005-2010: Regional Priorities. 55 pp.
Bhatia VS, Piara Singh, SP Wani, Kesava Rao and K Srinivas. 2006. Yield gap analysis of soybean, groundnut, pigeonpea, and chickpea in India using simulation modeling. Global Theme on Agroecosystems, Report No. 31, Patancheru 502324. Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 149 pp.
Bhattacharyya T, Chandran P, Ray SK, Mandal C, Pal DK, Venugopalan MV, Durge SL, Srivastava P, Dubey PN, Kamble GK, Sharma RP, Wani SP, Rego TJ, **Ramesh V** and **Manna MC.** 2006. Morphological Properties in red and black soils of selected benchmark spots in semi-arid tropics of India. Global Theme on Agroecosystems Report No. 21. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 100 pp.
Bhattacharyya T, Chandran P, Ray SK, Mandal C, Pal DK, Venugopalan MV, Durge SL, Srivastava P, Dubey PN, Kamble GK, Sharma RP, Wani SP , Rego TJ, **Ramesh V** and **Manna MC.** 2006. Estimation of carbon stocks in red and black soils of selected benchmark spots in semi-arid tropics of India. Global Theme on Agroecosystems Report No. 28. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 86 pp.
CHUC NT, 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 502324. Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 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 (ICRISAT). 52 pp.
Mashingaidze AB, Govere I, Rohrbach D, Lewis L, Twomlow S and Mazvimavi K. 2006. "Review of NGO Efforts to Promote Conservation Agriculture in Zimbabwe, 2006/06 Season". A report submitted to FAO. University of Zimbabwe and ICRISAT Bulawayo. 49 pp.
MATI BM. 2006. Enterprise Budget and Investment Study of Livestock under Irrigated Systems in Kenya. Working Paper No. 5. Nairobi, Kenya: International Livestock Research Institute (ILRI). 18 pp. http://www.ilri.cgiar.org/data/livelihood/Investment/EnterpriseBudget.pdf

Monographs:

MATI BM. 2006. Preliminary Assessment of Policies and institutional frameworks with bearing on agricultural water management in Eastern & Southern Africa. Report of a baseline study. SWMnet Working Paper 11. 62 pp.
Mazvimavi K, Rohrbach DD and Murendo C. 2006. Technical Advice and Monitoring of Fertilizer Distribution. A report submitted to COSV. ICRISAT Bulawayo. 8 pp.
Mazvimavi K, Rohrbach DD and **Pedzisa T.** 2006. Seed Fair Post Planting Monitoring, 2005/06 Cropping Season. An Interim report submitted to FAO. ICRISAT Bulawayo. 7 pp.
Mazvimavi K, Rohrbach D, **Pedzisa T** and Musitini T. 2006. A Review of Seed Fair Operations and Impacts in Zimbabwe. A report submitted to FAO. ICRISAT Bulawayo. 36 pp.
Ndjeunga J, Ntare BR, Waliyar F and Ramouch M. 2006. Groundnut Seed Systems in West Africa: Current Practices, Constraints and Opportunities. CFC Technical Paper No 40. PO. Box 74656, 1070 BR Amsterdam, The Netherlands: Common Fund for Commodities; Patancheru, India: International Crops Research Institute for the Semi-Arid Tropics. 232 pp.
Nigam SN, ARUNA R, Giri DY, Ranga Rao GV and Reddy AGS. 2006. Obtaining Sustainable Higher Groundnut Yields: Principles and Practices of Cultivation. Information Bulletin No. 71. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India. 41 pp.
PADMAJA R, BANTILAN MCS, **Parthasarathy D** and **Gandhi BVJ**. 2006. Gender and social capital mediated technology adoption. GT-MPI Progress Report No 138. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 40 pp
Pande S, **Gupta R, Dahiya SS, Chauhan YS, Singh S, Singh UP, Jat ML, Singh SS,** Sharma HC, Rao JN and **Chandna PC.** 2006. Identification, Adoption and Expansion of Extra Short Duration Pigeonpea Variety ICPL 88039 in Rice and Wheat Cropping Systems of the Indo-Gangetic Plains of India. Technical Bulletin Series No. 8. New Delhi, India: Rice-Wheat Consortium, International Wheat and Maize Research Center (CIMMYT). 50 pp.
Robert Paarlberg, David Wafula, Isaac Minde, JUDI WAKHUNGU. 2006. a) Projected Farm Income Gains in the COMESA-ASARECA Region from Commercialization of Bt Maize; b) Projected farm Income Gains in the COMESA-ASARECA Region from Commercialization of Bt Cotton; c) Food Aid Import Policies in the COMESA-ASARECA Region: The Costs and Benefits of Current Policy Options; d) Commercial Export risks from Approval of Genetically Modified (GM) Crops in the COMESA-ASARECA Region. RABESA Report Nos.1-4. ACTS Press, Nairobi, Kenya. 119 pp.
Sharma HC. 2006. Integrated pest Management Research at ICRISAT: Present Status and Future Priorities. Patancheru, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 43 pp.
Subrahmanyam S, Bezkorowajnyj P, Shiferaw B, Wani SP, Parthasarathy RP and Nageswara RGD. 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

Bulletins:

Borikar ST, Kalpande HG, Syed Ismail D, Mamidwar CHR, Ashok S Alur and Ch Ravinder Reddy. 2006. Improved production technologies of sorghum for Maharastra (In Marathi). CFC-FAO-ICRISAT Project, Global Theme on Crop Improvement, ICRISAT, Patancheru, AP. 16pp
Borikar ST, Kalpande HG, Syed Ismail D, Mamidwar HR, Ashok S Alur, Ravinder Reddy Ch, Tripathi CM and Birajdhar S. 2006. Improved production technologies of pearl millet for Maharastra (In Marathi). CFC-FAO-ICRISAT Project, Global Theme on Crop Improvement, ICRISAT, Patancheru, AP. 11pp
Cooper P, Dimes J, Rao KPC, Shapiro B, Shiferaw B and Twomlow S. 2006. Coping better with current climate variability in the rain-fed farming systems of sub-Saharan Africa: A dress rehearsal for adapting to future climate change? GTAE Report No. 27. P.O Box 39063-00623, Nairobi, Kenya. ICRISAT. 24pp
Dar WD and BANTILAN MCS. 2006. Science with a human face. Pages 171-173 in The Hindu Survey of Indian Agriculture: Can technology make agriculture viable? Chennai, India: The Hindu.
Khairwal IS, Rai KN, **Rajpurohit BS** and **NIRWAN B**. 2006. Pearl millet cultivars for drought prone environments. All India Coordinated Pearl Millet Improvement Project (ICAR), Agricultural Research Station, Mandor, Jodhpur, Rajasthan, India. 32 pp.
Nigam SN, ARUNA R, Giri DY, Ranga Rao GV and Reddy AGS. 2006. Obtaining sustainable higher groundnut yields: Principles and practices of cultivation. Information Bulletin no. 71, Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Bulletins:

Pande S, *Gupta R*, **Dahiya SS**, Chauhan YS, **Singh S**, **Singh UP**, **Jat ML**, **Singh SS**, Sharma HC, Rao JN and *Chandna PC*. 2006. Reintroduction of Extra Short Duration Pigeonpea (ICPL 88039) in Rice-Wheat Cropping Systems of the Indo-Gangetic Plains. RWC Technical Bulletin No. 9. RWC-ICRISAT, NASC Complex, Pusa, New Delhi 110 012, India. 48 pp.
Ravinder Reddy Ch, Ashok S Alur**, Varaprasad Reddy KM** and **Rajashekar Reddy A**. 2006.Improved production technologies of sorghum for Andhra Pradesh(In Telugu). CFC-FAO-ICRISAT Project, Global Theme on Crop Improvement, ICRISAT, Patancheru, AP. 16pp
Ravinder Reddy Ch., Ashok S Alur, **Varaprasad Reddy KM** and **A Rajashekar Reddy**. 2006. .Improved production technologies of pearl millet for Andhra Pradesh (In Telugu). CFC-FAO-ICRISAT Project, Global Theme on Crop Improvement, ICRISAT, Patancheru, AP. 11pp
Reddy BVS, **Ramesh S**, **Madhusudhana R** ARUNA REDDY C and SANJANA REDDY P. 2006. Population Improvement in Sorghum. Information Bulletin no.73. International Crops Research Institute for the Semi-Arid Tropics. Patancheru 502324, Andhra Pradesh, India: ISBN 92-9066-492-4. Order Code IBE 073. 64 pp.
Singh SK, Masood Ali, Nigam SN, **Roy Burman R** and **Chandel RS.** 2006. Validation and transfer of pulse production technology through farmer participatory approach. Information Bulletin. Indian Institute of Pulses Research, Kanpur 208 024.
Thakur RP, Reddy BVS, INDIRA S, Rao VP, Navi SS, Yang XB and Ramesh S**.** 2006. Sorghum Grain Mold. Information Bulletin No. 72. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India. 32pp.
Traore S. 2006. Battling desertification with decision support software. ICT-Update 31, March 2006. [http://ictupdate.cta.int/index.php/article/frontpage/49]

Abstracts:

Alexander G, Vijay PM, Sharma HC, Saxena KB, Khan AA and Blümmel M. 2006. Influence of alkaloids and flavonoids on nutritional quality of pigeonpea forages. [Abstract] Pages 320-321 *in* Strengthening Animal Nutrition Research for Food Security, Environment Protection and Poverty Alleviation (Pattanaik AK, Narayan Dutta and Verma AK, eds.). Proceedings of VIth Animal Nutrition Association Biennial Conference, September 15-17, 2006, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, India.
Cooper PJM, Dimes JP, Rao KPC, Shapiro B, Shiferaw B and Twomlow S. 2006. Coping better with current climatic variability in rain fed farming systems of sub-saharan Africa : A dress rehersal for adpating to future climate change. [Volume of Abstracts] Page 34 *in* 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process. Lilongwe, Malawi, 1-3 Septmber 2006.
Dhliwayo C, Makurira H, Mupangwa W, Love D and Twomlow S. 2006. An on farm comparison of conservation agriculture practices and conventional farm practices on soil hydrology and maize yield. [Volume of Abstracts] *In* 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process'. Lilongwe, Malawi, 1-3 November 2006.
Dileepkumar Guntuku, **Sreenath Dixit** and Balaji Venkataraman. 2006. Rural Knowledge Centers as Facilitators of New Learning Opportunities for the Rural Families: a case study. Extended abstract Contributed to ICSI2006 (International Conference on Statistics and Informatics in Agricultural Research conference), New Delhi, India. 27-30 December, 2006, available at http://www.iasri.res.in/icsi2006/theme3/balaji.pdf.
Farid Waliyar, Lava Kumar P, Sharma KK, Nigam SN and Hoisington D. 2006. Integrated multidisciplinary approach for containing aflatoxin-linked malnutrition in humans and animals. [Abstract] Page 6 *in* Proceedings of Biotechnology approaches for alleviating malnutrition and human health, 9-11 Jan 2006, University of Agricultural Sciences, Gandhi Krushi Vignyan Kendra, Bangalore 560 065, Karnataka, India.
Jiang H, Ren X, Liao B, Lei Y, Wang S, Li D, Xu Z, Hua W, MACE E, Upadhyaya HD, Nigam SN and **Zhang X**. 2006. SSR and AFLP markers for bacterial wilt resistance in groundnut (*Arachis hypogaea* L.). [Abstract] Page 103 *in* International Groundnut Conference on Groundnut Aflatoxin and Genomics, 5-9 November 2006, Guangzhou, Guangdong, China.
Jiang H, Ren X, Liao B, Lei Y, Wang S, Li D, Xu Z, Hua W, Mace E, Upadhyaya H, Nigam SN and **Zhang X**. 2006. SSR and AFLP markers for resistance to bacterial wilt in groundnut (*Arachis hypogaea* L.). Page 103 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.

Abstracts:

Kileshye Onema J-M, Mazvimavi D, Love D and MUL M. 2006. Effects of dams on river flows of Insiza River, Limpopo Basin, Zimbabwe. World Water Week, Stokholm, Sweden, 20-26 August, 2006.
Love D, **Gumbo B** and **Nyabeze W**. 2006. Managing risk, mitigating drought and improving water productivity in the water scarce Limpopo Basin: highlights of some integrated water resources management solutions. *In* SADC Land and Water Management Applied Research Programme Scientific Symposium "Land and Water Management for Sustainable Agriculture", Lilongwe, Malawi, 13th – 16th February 2006.
Love D, **Moyce W** and **Ravengai S**. 2006. Livelihood challenges posed by water quality in the Mzingwane and Thuli river catchments, Zimbabwe. 7th WaterNet/WARFSA Symposium, Lilongwe, Malawi, November 2006.
Love D, Twomlow S, Ulenbrook S and van der Zaag P. 2006. Long term trends in climate and runoff in the Limpopo Basin, Zimbabwe and their livelihood implications. [Volume of Abstracts] Page 55 *in* Poster Presentation 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process. Lilongwe, Malawi, 1-3 Septmber 2006.
Love D, Uhlenbrook S, **Madamombe E**, Twomlow S and van der Zaag P. 2006. An evaluation of climate and run-off variability and associated livelihood risks in the Mzingwane Catchment, Limpopo Basin, Zimbabwe. Water Institute of Southern Africa Biennial Conference and Exhibition, Durban, South Africa, May 2006.
Meena Kumari KVS, Ankaiah R, Vilas A Tonapi and Ravinder Reddy Ch. 2006. Seed health status of certified and farmer seed samples of Groundnut varieties in Andhra Pradesh. [Abstract (PS II-188): (compendium of Abstracts)] Page 93 *in* Paper presented at presented at XII National Seed Seminar on "Prosperity through quality seed", organized by Indian Society of Seed Technology, New Delhi and Acharya NG Ranga Agricultural University, Hyderabad, 24-26 february, 2006.
Moyce W, Mangeya P, Owen RJS and Love D. 2006. Alluvial aquifers for potential safe water storage in semi-arid areas: case study of the Lower Mzingwane Catchment, Limpopo Basin, Zimbabwe. World Water Week, Stokholm, Sweden, 20-26 August, 2006.
Moyo L, Senzanje Makurira H and Twomlow S. 2006. An assessment of soil and water management techniques towards rainwater productivity in semi-arid Gwanda District, Limpopo Basin. [Volume of Abstracts] Page 48 *in* Power Point Presentation 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process. Lilongwe, Malawi, 1-3 Septmber 2006.
NGWENYA PT, Love D, **Mhiza A** and Twomlow S. 2006. Effects of grazing management on rangeland soil hydrology, Insiza, Zimbabwe. [Volume pf Abstracts] Page 47 *in* Power Point Presentation 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process'. Lilongwe, Malawi, 1-3 November 2006.
Nyabeze W, Gumbo B and Love D. 2006. Olifants River Basin: the process of basin closure. World Water Week, Stokholm, Sweden, 20-26 August, 2006.
Pathak M, SHARMA M, Narayana Rao J and Pande S. 2006. Phytophthora Blight of Pigeonpea in the Deccan Plateau of India. [Abstract] Page 32 *in* National Symposium on Emerging Plant Diseases their Diagnosis and Management, 31Jan - 2Feb 2006, Department of Botany, University of West Bengal, Siliguri, West Bengal, India.
Roothaert RL, Olufajo OO, Bezkorowajnyj PG, Reddy R, Tonapi VA and Seetharama N. 2006. Seed innovation systems of food feed crops: New perspectives for the small holder farmers in the tropics. Page 311 *in* Proceedings of International Conference on Livestock Services. 17-19 April, 2006, Beijing, China. Organized by Chinese Academy of Engineering (CAE), Ministry of Agriculture (MOA), Peoples Republic of China, and Chinese Academy of Agricultural Sciences (CASS).
SHARMA M, Pathak M, Narayana Rao J and Pande S. 2006. Comparison of resistance screening techniques for Ascochyta blight and Botrytis grey mould in chickpea. [Abstract] Page 33 *in* National Symposium on Emerging Plant Diseases their Diagnosis and Management, 31Jan - 2Feb 2006, Department of Botany, University of West Bengal, Siliguri, West Bengal, India.
Srinivasarao Ch. 2006. Potassium Availability, Distribution and Categorization of Various Soil Types Under Different Rainfed Production Systems of India. Pages 152-10 *in* 3.2 B: Dryland Conservation Technologies: Innovations for Enhancing Productivity and Sustainability 18th World Congress of Soil Science, 15th July, 2006, Philadelphia, International Union of Soil Science, USA. http://crops.confex.com/crops/wc2006/techprogram/P11663.HTM
Srinivasarao Ch, **Vijayasankarbabu M, Vittal KPR, Venkateswarly B, Yallamandareddy Kundu S** and **Gajbhiye PN**. 2006. Effect of 20 years of Cropping, Fertilization, Farm Yard Manure and Groundnut Shells Application on Water Retention, Chemical and Biological Properties of Alfisol and Pod Yields of Rainfed

Abstracts:

Groundnut under Arid Climate. Pages 152-1 *in* 3.2 B: Dryland Conservation Technologies: Innovations for Enhancing Productivity and Sustainability 18th World Congress of Soil Science, 15th July, 2006, Philadelphia, International Union of Soil Science, USA. http://crops.confex.com/crops/wc2006/techprogram/P11667.HTM
Thakur RP. 2006. Pathogen diversity and genetic management of downy mildew in pearl millet. [Abstract] Pages 63-64 *in* Paper presented at the national Symposium on Biodiversity and biotechnology: Research and Development needs in Edible Mushrooms and Crop Disease Management. Annual Meeting of Indian Society of Mycology and Plant Pathology, GB Pant University of Agriculture and Technology, Pantnagar 263 145, Uttaranchal, 9-11 November 2006.
Vilas A Tonapi, Ravinder Reddy Ch, Elangovan M and Seetharama N. 2006. Sorghum and Millet Genetic Resources Management Network Activity Model (NAM) vis-à-vis Community Systems as the Harbinger of Biodiversity Protection in India. [Compendium of abstracts] Page 57 *in* Oral paper presented at National Conference on Agro-biodiversity, February 12-15, 2006, Organized by National Biodiversity Authority, Chennai, 12-15 February 2006.
Vilas A Tonapi, Ravinder Reddy Ch, Elangovan1 M., Venkatesh Bhat and Seetharama N. 2006. Enabling Farmers Rights as the Edifice of Biodiversity Protection in India. [Compendium of abstracts] Page 123 *in* Oral paper presented at National Conference on Agro-biodiversity, February 12-15, 2006, Organized by National Biodiversity Authority, Chennai, 12-15 February 2006.
Vilas A Tonapi, Harinath Babu P, Ansari NA, Varanavasiappan S, Ravinder Reddy Ch, Navi SS, Umakanth AV, Elangovan M, Meenakumari KVS and Seetharama N. 2006. Effect of seed colouring on seed quality of cereals, pulses and oil seeds. [Abstract (PS II-289):compendium of Abstracts] Page 140 *in* Paper presented at presented at XII National Seed Seminar on "Prosperity through quality seed", organized by Indian Society of Seed Technology, New Delhi and Acharya NG Ranga Agricultural University, Hyderabad, 24-26 February, 2006.
Waliyar F, Lava Kumar P, Nigam SN, Sharma KK, ARUNA R, Hoisington D and Gowda CLL. 2006. Strategies for the management of aflatoxin contamination in groundnut. Pages 32-33 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Waliyar F, Nigam SN, Craufurd PQ, Wheeler TR, Reddy SV, **Subramanyam K, Yellamanda Reddy T, RAMA DEVI K,** Upadhyaya HD and Lava Kumar P. 2006. Evaluation of new *Aspergillus flavus* resistant groundnut varieties for agronomic performance in multi-location on-farm trials in Andhra Pradesh, India. Page 40 *in* Program and Book of Abstract, International conference on Groundnut aflatoxin management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.

Brochures/Pamphlets:

Balaji V. 2006. ICRISAT initiatives in Technology-Mediated Distance Learning for Higher and Continuing Education: The GO-FAU and SAEC-DE Projects
Balaji V. 2006. The Virtual Academy for the Semi-Arid Tropics (VASAT): A strategic communication and distance education coalition hosted by ICRISAT.
Balaji V. 2006. Using ICT for Improved Extension: More effective drought preparedness through knowledge sharing.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
Gerard B. 2006. Detailed map based on orthorectified Spot 5 imagery of the Fakara region, Niger at 1/30,000 scale.
GV Ranga Rao 2006. Production of *Helicoverpa* nuclear polyhedrosis virus (HNPV) at village level.

Brochures/Pamphlets:

Hoisington D. 2006. The Molecular Breeding Center of Excellence at ICRISAT. Striding towards efficient breeding and research in India. 2006
Hove L. 2006. ICRISAT. 2006. Do you have Draft Power? Use Ripper Tine to Increase Your Yields!
Hove L. 2006. ICRISAT. 2006. Grow More Grain Using Planting Basins
Hove L. 2006. ICRISAT. 2006. How To Use Small Quantities of Nitrogen Fertilizer
Hove L. 2006. ICRISAT. 2006. Lima uzuze isivuno esingcono ngokugebha amagodi
Hove L. 2006. ICRISAT. 2006. Mashandisirwo efetiraiza shoma yeNitrogen
Hove L. 2006. ICRISAT. 2006. Ukusetshenziswa kwe fethalayiza ye- Nitrogen ngesilinganiso esincinyane
Hove L. 2006. ICRISAT. 2006. Ulakho Okokulimisa NA? Sebenzisa iRipper Tine Wengeze Isivuno Sakho!ICRISAT. 2006. Unezvekurimisa here? Shandisa Ripper Tine kuwedzera Goho rako!
Hove L. 2006. ICRISAT. 2006. Wedzera Goho Nekushandisa Makomba
Jones RB. 2006. Seed Enterprise Enhancement Development Services (SEEDS).
Kesava Rao AVR, Piara Singh, Wani SP and Srinivas K. 2006. Agroclimatic Characterization and Assessment of Potential for Increasing Crop Productivity at Adarsha Watershed, Kothapally, Andhra Pradesh.
Kesava Rao AVR, Piara Singh, Wani SP and Srinivas K. 2006. Agroclimatic Characterization and Assessment of Potential for Increasing Crop Productivity in TATA-ICRISAT-ICAR Benchmark Watersheds.
Mati BM. 2006. IMAWESA Project brochure
Mati BM. 2006. Flier of the Resolution of the 2nd workshop on agricultural water management in Eastern & Southern Africa.
Mazvimavi K, Rohrbach D, Twomlow S and Hove L. 2006. Building sustainable fertilizer delivery systems for drought prone regions. ICRISAT-Bulawayo Breifing Note 2, September 2006.
MGONJA MA, **Mharapara I, Takawira M** and **Pambirei N**. 2006. Increased food security and income in the Limpopo Basin through integrated crop, water and soil fertility options and link to markets. Filed day brochure.
Mula Rosana P. 2006. Greening Drylands and Improving Livelihoods
Ndjeunga J and **Echekwu CA**. 2006. Enhancing business skills of small-scale rural entrepreneurs: A technical training note. Adapted from the Handbook written and edited by Sonia David and Beth Oliver at the International Centre for Tropical Agriculture (CIAT).
Ndjeunga J, BANTILAN MCS, Rao KPC and Ntare BR. (eds). 2006. Impact Assessment of Agricultural Technologies in West Africa. Summary Proceedings of a Training Workshop on Impact Assessment: Technical Notes & Exercises. 12-16 July 2004. Proceedings of the Training Workshop on Impact Assessment of Agricultural Technologies in West Africa, Bamako-Mali. International Crops Research Institute for the Semi-Arid Tropics
Pande S and Rao JN 2006. Groundnut variety ICGV 91114-information brochure (in English).
Pande S, **Urkurkar JS**, **Sharma ML** and Gaur PM. 2006. Rice based chickpea production technology – (in Hindi).
Pasternak Dov. 2006. AMG Success Story Brochure for USAID-WA.
Prabhakar Pathak. 2006. Hydrological and water quality monitoring at benchmark watersheds in Madhya Pradesh and Rajasthan.
Ravinder Reddy Ch. 2006. Managing grain molds and mycotoxins in sorghum and pearl Millet.
Reddy BVS, Rai KN and *Dakheel A*. 2006. Crop diversification and farmers' livelihood improvement in Central Asia: new opportunities with sorghum and pearl millet (Dakheel, CG or else?).
Reddy BVS, Rai KN and *Dakheel A*. 2006. Salinity tolerance research on sorghum and pearl millet: progress and prospects (Dakheel, CG or else?).
Reddy BVS, **Ramesh S**, SANJANA REDDY P, *Karuppan Chetty SM* and **Palaniswamy AR**. 2006. Sweet sorghum: food, feed, fodder and fuel crop
Saxena KB. 2006. Hybrid Pigeonpea–Seeds of Excellence.
Sharma KK. 2006. ABI/Incubators Conference, Brochure & Posters.
Sharma KK. 2006. Agri-Business Incubator@ICRISAT, Brochure.
Sharma KK. 2006. Agri-Business Incubator@ICRISAT, Pamphlet.
Sharma KK. 2006. Agri-Science Park@ICRISAT, Brochure.
Sharma KK. 2006. Agri-Science Park@ICRISAT, Pamphlet.
Sreedevi TK. 2006. Biodiesel Crops as Candidates for the Rehabilitation of Degraded Lands in India – Research @ ICRISAT.
Sreedevi TK. 2006. Crop Seminar on Watershed Development: Live Telecast by Doordarshan.

Brochures/Pamphlets:

Twmolow S. 2006. ICRISAT Bulawayo, 2006. Do you have draft power? Use ripper tine to increase your yields! (English, Ndbele, Shona).
Twmolow S. 2006. ICRISAT Bulawayo, 2006. Grow more grain using planting basins (English, Ndbele, Shona).
Twmolow S. 2006. ICRISAT Bulawayo, 2006. How to use small quantities of nitrogen fertilizer (English, Ndbele, Shona).
Twomlow S and Hove L. 2006. Is conservation agriculture a viable option for vulnerable households? - ICRISAT-Bulawayo Briefing Note 4, September 2006.
Twomlow S and Rohrbach D. 2006. Achieving Sustained Gains in the Food Security of Vulnerable Households. ICRISAT-Bulawayo Briefing Note 1, September 2006.
Twomlow S, Tabo R, Gerard B and Dimes J. 2006. A Pathway to Africa's Green Revolution. ICRISAT's perspective on fertilizer interventions for semi-arid areas. Pamphlet prepared for the African Fertilizer Summit, Abuja, Nigeria. June 2006.
Vamsidhar Reddy TS. 2006. Joint treading of the path of Natural Resource Management (NRM) and sustainable rural livelihoods in watersheds: Salient features on institutions and impacts**.** Flier displayed in the TATA review, 10 – 11 January 2007.
Varshney Rajeev. 2006. The Molecular Breeding Center of Excellence at ICRISAT. Striding towards efficient breeding and research in India. 2006
Waliyar F. 2006. Agri Science Park brochure on corporate communication
Waliyar F. 2006. Flyer on Agric Science Park on various components (prepared for AGM).
Waliyar F. 2006. Flyer on Clientele distribution prepared for Global Forum for Business incubators
Wani SP. 2006. Agroclimatic Characterization and Assessment of Potential for Increasing Crop Productivity in TATA-ICRISAT-ICAR Benchmark Watersheds
Wani SP. 2006. Biodiesel Crops as Candidates for the Rehabilitation of Degraded Lands in India – Research @ ICRISAT
Wani SP. 2006. Crop Seminar on Watershed Development : Live Telecast by Doordarshan
Wani SP. 2006. Enhanced Land Productivity and Livelihood Options Increased Rural Incomes in Watersheds of Madhya Pradesh and Rajasthan.
Wani SP. 2006. Hydrological and water quality monitoring at benchmark watersheds in Madhya Pradesh and Rajasthan.
Wani SP. 2006. Joint Treading of the Path of Natural Resource Management (NRM) and Sustaining Rural Livelihoods in Watersheds : Salient Features on Institutions and Impacts.
Wani SP. 2006. Seed Priming – Simple Way to Use Rice fallows in Madhya Pradesh.

Invited Seminars:

BANTILAN MCS. 2006. CII - ICRISAT workshop "Corporate and Science & Technology"
BANTILAN MCS. 2006. Institutional innovation systems at ICRISAT: facilitating synergies in agricultural research for development. Presented at International Conference on Social Science Perspectives in Agricultural Research and Development, 15-18 Feb 2006, New Delhi: India.
BANTILAN MCS. 2006. Poverty dynamics and development pathways: VLS generation II. Invited seminar presented at Cornell University, 4 August, 2006.
Belder P. 2006. Presented project proposal on micro-irrigation project to local NGOs operating in Matabeleland at Hlekweni Friends, Bulawayo, 9 May 2006.
Belder P. 2006. Stakeholder workshop, 6 October 2006, Bronte hotel, Harare. Presented results of micro-irrigation survey.
BHATNAGAR-MATHUR P and Sharma KK. 2006. Genetic Transformation, Crop Improvement & Scientific Advancements: Status, Issues and Future Directions. Workshop on Reorientation on Biosafety in GM crops for Officials of Government of Andhra Pradesh, *In* Collaboration with All India Crop Biotech Association, TERI & APNLBP, Hyderabad, December 19, 2006.
Chander Rao S, Lava Kumar P, Reddy AS, Swamy Krishna S, Waliyar F, Nigam SN and Sharma KK. 2006. *In* Symposium on Management of Vector-Borne Viruses, pp. 101-102. 16th Annual Convention of Indian Virological Society, Feb. 7-10, 2006, ICRISAT, India

Invited Seminars:

Dar WD, **BHATNAGAR-MATHUR P** and Sharma KK. 2006. Application of Modern Biotechnology for Improving Livelihoods in the Semi-Arid Tropics -- ICRISAT's Initiatives *in* International Conference on “Agriculture for Food, Nutritional Security and Rural Growth, BP Pal Centenary Celebration, TERI, New Delhi, 25-27 May 2006.
Dar WD, Wani SP and Mula RP. 2006. Asian Perspective on Programs and Strategies for Sustainable Dryland Agriculture. In International Multi-Sectoral Joint Conference on MultiFunctionality of Sustainable Agriculture and Mitigating Land Degradation & Deforestation for Improved Food Security, Livelihood and Biodiversity. November 27- December 1, 2006 at Manila and Cebu, Philippines.
Dar WD. 2006. A year of hope and achievements Annual day speech, 14 December 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Agriculture for economic empowerment of rural India Panelist, Session on Agriculture for economic empowerment of rural India, International conference on Agriculture for food, nutritional security, and rural growth organized by TERI, 26 May 2006, New Delhi, India.
Dar WD. 2006. Biological Approaches to Crop Production and Protection Inaugural address, Learning Workshop on Biological Approaches for Crop Production and Protection, 7-12 Aug 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Converging interests carve out a future for the dryland farmer - Inaugural address, on July 19, 2006 at the Tata-ICRISAT-ICAR Project review and Planning Workshop, ICRISAT, Patancheru, Andhra Pradesh, India.
Dar WD. 2006. Creating a secured future for the poor Message, Vision and Strategy Workshop, 23-24 February 2006, ICRISAT-Patancheru, Andhra Pradesh, India.
Dar WD. 2006. Developing fertilizer intervention for semi-arid areas presented at the Africa Fertilizer summit, on behalf of Future Harvest Alliance of the CGIAR on June 09 2006 in Abuja, Nigeria.
Dar WD. 2006. Enhanced Utilization of Sorghum and Pearl Millet to Improve the Livelihoods of Asian Farmers Inaugural address, CFC-FAO-ICRISAT Farmers' meet and inauguration of storage structure, drier shed and sorghum ear head drier, 3 November 2006, Udityal cluster, Balanagar mandal, Mahabubnagar, Andhra Pradesh, India.
Dar WD. 2006. Gearing the Philippines towards creating international synergies for the poor Keynote speech, 16th National Convention of the Philippine Association of Research Managers on “Quality management system for enhanced RDE productivity and accountability” , 18-21, April 2006, Teatro Ilocandia, Mariano Marcos State University, Batac, Ilocos Norte, The Philippines.
Dar WD. 2006. Harmonizing Biosafety Regulations for Transgenic Crops in the Asia-Pacific Region Chairman's address, Workshop on Biosafety regulations for transgenic crops and the need for harmonizing them in the Asia-Pacific region, 31 July – 2 August 2006, ICRISAT, Patancheru, Andhra Pradesh, India 502 324.
Dar WD. 2006. Helping build a world without hunger Welcome address during the visit of Dr Jacques Diouf, Director-General of the Food and Agriculture Organization of the United Nations (FAO) , 04 January 2006, ICRISAT Patancheru, Andhra Pradesh, India.
Dar WD. 2006. IFAD and ICRISAT: Triumphant partners in farmer participatory research and extension Welcome address, IFAD TAG 532-ICRISAT Project Completion Meeting, 8-10 May 2006, ICRISAT, Patancheru 502 324, India.
Dar WD. 2006. Intervention and implementation needs for sustainable dryland development presented by Dr. William Dar, Director General, ICRISAT, on behalf of Alliance Executive of the CGIAR Future Harvest centers, in Tunis, Tunisia, 19 June 2006.
Dar WD. 2006. Leading and Learning: Partners in Progress Launch of The Association of International Schools of India (TAISI), 25 Sept 2006, Closing remarks,ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Leading ICRISAT to Excellence and Relevance Plenary speaker, 1st Outstanding Young Scientists, Inc. Annual convention, 11 July 2006, Manila Hotel, The Philippines.
Dar WD. 2006. Making Biotechnology Work for the Poor Welcome address delivered at the International Workshop on Application of Genomics to Chickpea , Pigeonpea and Peanut Improvement, 6-9 March 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Making Safety Everybody's Business Inaugural address, Safety Day, 8 August 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Multiplying the message: Communicating agri-biotechnology to mediapersons Inaugural speech delivered at the Media Workshop on Reporting Biotechnology: Issues and Opportunities for the Telugu/English News Media , 7 August 2006, at Patancheru.

Invited Seminars:

Dar WD. 2006. New Champions of Pearl Millet Research for Development Closing remarks, International Training Course on Pearl Millet Improvement and Seed Production, 15 May 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. New technologies for the economic empowerment of rural India Lead speaker, Session on New technologies: Description, International conference on Agriculture for food, nutritional security, and rural growth organized by TERI, 26 May 2006, New Delhi, India. (PPT Presentation)
Dar WD. 2006. Nurturing Partnerships for Sustainable Development Welcome address, the Confederation of Indian Industry (CII)-ICRISAT workshop on Corporate and Science & Technology Institutions Partnership for Inclusive and Sustainable Development and Economic Growth, 27 Feb 2006, ICRISAT Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Participatory Plant Breeding and Knowledge Sharing: ICRISAT's Role in the Semi-Arid Tropics of the World - Inaugural address at the International symposium on Participatory Plant Breeding and Knowledge Management for Strengthening Rural Livelihoods , on 17 July 2006, at the M S Swaminathan Research Foundation, Chennai, Tamil Nadu, India .
Dar WD. 2006. Reaching out to the Rural Learner,Opening up Opportunities Delivered at the Roundtable Discussion on Setting Up Online Grids of Educational and Extension Materials and for Capacity Strengthening , 15 February 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Role of International Agricultural Research in Achieving MDGs Presentation for the plenary session on global initiatives to achieve the MDGs, 93rd Indian Science Congress, ANGRAU, 04 January 2006, Hyderabad, Andhra Pradesh, India.
Dar WD. 2006. Role of international agricultural research in achieving MDGs and need for new partnerships Presented in the Plenary session of the GFAR 2006 Triennial Conference, 9 November 2006, New Delhi, India.
Dar WD. 2006. Science and Technology in Disaster Management Inaugural address delivered at the National workshop on Disaster Management – Role of Scientific and Technical Institutions', 24 March 2006, Dr MCR HRD Institute of Andhra Pradesh, Jubilee Hills, Hyderabad, Andhra Pradesh, India.
Dar WD. 2006. Shaping a Productive Research Agenda for Pearl Millet Welcome speech, Pearl Millet Scientists' Field Day, 14 Sept 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Sorghum: The Versatile Crop for the Poor SAT Farmer Welcome and inaugural address, Sorghum Scientists' Field Day, 28 September 2006, Pradesh, India. ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Sweet sorghum for the fuel of the future Inaugural address delivered at the Workshop on “Sweet sorghum for improving the livelihood of farmers” organized by the Federation of Farmers Associations, AP, 31 Mar 2006, FAPCCI Bhavan, Red Hills, Hyderabad, Andhra Pradesh, India.
Dar WD. 2006. The Center of Excellence: The quest for new horizons Inauguration of the Center of Excellence for Genomics, 13 December 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. THE DRYLANDS OF HOPE Keynote address, Conference on Strength Based Strategies 2006, 11 Nov 2006, NISIET, Hyderabad , India.
Dar WD. 2006. The New ICRISAT and its Impacts in Sub-Saharan Africa 23 October 2006, Ottawa, Canada.
Dar WD. 2006. The Seeds of Hope Welcome address, Launch meeting of the ISOPOM Project on Development and popularization of ‘model' seed system (s) for quality seed production of major legumes to ensure seed-sufficiency at the village level , 16 Nov 2006, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.
Dar WD. 2006. Towards institutional innovations at ICRISAT Welcome remarks, Global In-house Review Meeting,20-22 February 2006, ICRISAT-Patancheru, Andhra Pradesh, India.
Dar WD. 2006. Tunis UNESCO Conference- Why Invest in Drylands welcoming remarks by Dr. William Dar, Director General, ICRISAT, in Tunis,Tunisia,19 June 2006.
Dar WD. 2006. Turning Adversities into Opportunities Guest of honor and speaker, 90th Foundation Anniversary of the Benguet State University, 28 June 2006, La Trinidad, Benguet Province, the Philippines.
Dhillon MK, Sharma HC and Romeis J. 2006. Influence of *Bacillus thuringiensis* δ-endotoxins and *Helicoverpa*–resistant chickpea genotypes on development and survival of the parasitoid, *Campoletis chlorideae*. Page 12 *in* Annual Pulse Network Meeting 5-7 December 2006, Indo-Swiss Collaboration in Biotechnology, Department of Environmental Biology, University of Delhi, India.
Dhillon MK. 2006. Effects of Cytoplasmic Male-sterility on Expression of Resistance to Sorghum Shoot Fly, *Atherigona soccata* (Rondani) (Muscidae: Diptera) *in* 26th Annual Session of The Academy of Environmental Biology and National Seminar on Environmental Scenario: Challenges and Solutions, 23-25

Invited Seminars:

December 2006, School of Environmental Biology, Awadhesh Pratap Singh University, Rewa 486 003, Madhya Pradesh, India.
Gaur PM, Srivastava R, Gowda CLL, Pande S, Sharma HC, Sharma KK, Vadez V, Kashiwagi J, Krishnamurthy L, Varshney R and Hoisington D. 2006. Breeding chickpea for improved adaptation to the semi-arid tropical environments *in* International Conference on Sustainable Agriculture for Food, Bio-energy and Livelihood Security" to be held at Jabalpur, Madhya Pradesh, India during 14-16 February 2007.
Gaur PM. 2006. Chickpea breeding at ICRISAT. 14 March 2006, National Chemical Laboratory, Pune, India
Gaur PM. 2006. Revisiting chickpea research priorities in changing scenario of chickpea production and trade. Chickpea Scientists' Meet, 1 March 2006, Indian Institute of Pulses Research, Kanpur, India
Gérard B. 2006. Six hours lecture at Université catholique de Louvain for the course BAPA3008 (Enquête et vulgarisation en milieu tropical). Fall 2006.
Gérard B. 2006. Two hours lecture at Université catholique de Louvain for the course BRES2202 (Séminaire des ressources en eau et sols. Fall 2006.
GRENIER C, HAUSSMANN BIG, Kiambi D and Ejeta G. 2006. Marker assisted selection for *Striga* resistance in sorghum. Oral presentation at the International Symposium on Integrating New Technologies for Striga Control, November 5-11, 2006, Addis Ababa, Ethiopia.
Hash CT, Sharma A, Nepolean T and Senthilvel S. 2006. Development and application of tools for marker-assisted breeding in pearl millet. Plant & Animal Genome XIV, Jan 14–18 2006, Town & Country Hotel, San Diego, CA, USA. Final Abstracts Guide. W66. http://www.intl-pag.org/14/abstracts/
Hash CT. 2006. Biotechnology for Genetic Improvement of Sorghum and Millets. International Conference on "Biotechnology for Sustainable Agriculture and Agro-Industry", 9-11 Mar 2006, Pragati Resorts, Hyderabad, India.
Hash CT. 2006. Opportunities for application of molecular markers for sustainable crop production in stress environments: Sorghum and pearl millet. Plant Breeding Seminar Series: Breeding for Drought Stress Tolerance in Cereals. 24 Jan 2006, Cornell University, Ithaca, NY, USA.
Hoisington D, Vadez V, Hash CT, Senthilvel S, Sharma KK, Varshney R, Kashiwagi J, Rizvi SMH, Bidinger FR, Bantte K, JOTSNA DEVI J, BHATNAGAR-MATHUR P, Krishnamurthy L, Gaur PM, Nigam SN, Aruna R and Upadhyaya HD. 2006. Molecular approaches for improving water-stress tolerance of cereals and legumes in the semi-arid tropics *in* "Eiselen Foundation Conference on Food and Nutrition Security of the World: The Role of Biotechnology", 10-11 May, Hohenheim, Germany.
Hoisington D, Vadez V, Hash CT, Senthilvel S, Sharma KK, Varshney RK, Kashiwagi J, Rizvi SMH, Bidinger FR, Bantte K, **JYOTSANA DEVI M, BHATNAGAR-MATHUR P**, Krishnamurthy L, Gaur PM, Nigam SN, RUPAKULA A and Upadhyaya HD. 2006. Molecular approaches for improving water-stress tolerance of cereals and legumes in the semi-arid tropics *in* Biovision Conference, Alexandria, Egypt, 26-29 April, 2006.
Hoisington DA, MALLIKARJUNA N, Upadhyaya HD, Gaur PM, Nigam S, Saxena KB, Hash CT, Waliyar F, Kumar PL, Vadez V and Varshney R. 2006. Tapping crop diversity and genomics to tackle problems faced by farmers in the semi-arid tropics *in* ASA - CSSA – SSSA International Annual Meetings, Nov 12-16, Indianapolis, USA.
Hoisington DA, Varshney RK, Gwata E, Sharma H, Kashiwagi J and Gaur PM. 2006. Improving chickpea productivity for marginal environments in sub-Saharan Africa and Asia: An Introduction to Gates Foundation Proposal. Iinternational Workshop on Genomics-Enabled Improvement of Legumes, Pacific Grove, CA, USA, August 29- September 1, 2006
Hoisington DA. 2006. Challenges and opportunities for agri-biotechnology – Enhancing crops for the semi-arid tropics. Presented at the AgriBiotech 2006 1st International Conference on "Biotechnology for Sustainable Agriculture and Agro-Industry", 9-11 March 2006, Hyderabad, AP, India.
Hoisington DA. 2006. *Application of genomics for improving legumes at ICRISAT*. Presented at the "International Conference on Groundnut Aflatoxin Management and Genomics", 5-9 Nov 2006, Guangzhou, China.
Hoisington DA. 2006. *Legume research at ICRISAT*. Presented at the Third International Conference on Legume Genomics and Genetics, 9-13 April 2006, Brisbane, Queensland, Australia.

Invited Seminars:

Hoisington DA. 2006. Molecular approaches for improving the water-stress tolerance of cereals and legumes in the semi-arid tropics. Presented at the international conference “Food and Nutrition Security of the World: The Role of Biotechnology”, 10-11 May 2006, Universität Hohenheim, Hohenheim, Germany.
Hoisington DA. 2006. Molecular genomics strategies for improving water-stress tolerance of cereals and legumes in the semi-arid tropics. Presented at the GDEST Conference, 4 October 2006, Chennai, India.
Hoisington DA. 2006. *Predicting phenotypes from genotypes – the application of genomics in sorghum and pearl millet*. Presented at the Genomics-Assisted Breeding Workshop at the Plant and Animal Genome XIV International Conference, 14-18 January 2006, San Diego, CA USA.
JAYASHREE B. 2006. Presented seminar between Feb-March 2006, to the post-graduate students in Bioinformatics, IIIT (International Institute of Information Technology), Hyderabad, as part of Invited lecture series in advanced biology.
JAYASHREE B. 2006. Presented seminar between Feb-March 2006, to the post-graduate students in Bioinformatics, IIIT (International Institute of Information Technology), Hyderabad, as part of Invited lecture series in advanced biology.
JAYASHREE B. 2006. Presented seminar between Feb-March 2006, to the post-graduate students in Bioinformatics, IIIT (International Institute of Information Technology), Hyderabad, as part of Invited lecture series in advanced biology.
Jones RB. 2006. Guest speaker at the 17th Annual Congress of the South African National Seed Organization (SANSOR) during the open session of the SANSOR Agronomy Division on 3rd May 2006 at Kopanong Hotel & Conference Centre, Benoni, Gauteng, South Africa - Developing sustainable seed systems to support commercialization of small-scale agriculture in sub-Saharan Africa in collaboration with the South African seed industry.
Jones RB. 2006. Invited speaker at the African Seed Trade Association (AFSTA) 2006 Congress from 28-31st March 2006 at the Imperial Beach Hotel, Entebbe, Uganda - Facilitating access to publicly available germplasm to support the development of the seed industry.
Jones RB. 2006. Invited speaker at the New Seed Initiative for Maize in Africa (NSIMA) from 10-11th August 2006 at Kopanong Hotel & Conference Centre, Benoni, Gauteng, South Africa – The Seed Incubator Concept.
Kashiwagi J. 2006. Current research status of drought avoidance root traits in chickpea (*C. arietinum* L.) and the future. “Seminar series at Indian Institute of Pulses Research (IIPR)”, 21-23 May, Kanpur, India.
Kesava Rao AVR. 2006. DSSAT Crop Models and AEGIS/WIN. Invited Lecture on 14 October 2006 to the participating scientists to the “Refresher course on Information Technology in Agriculture for Effective Decision Support”, held at the National Academy of Agricultural Research Management (NAARM), Rajendranagar, Hyderabad.
Kesava Rao AVR. 2006. GIS Techniques in Drought Monitoring. Invited Lecture on 04 October 2006 to the participants of the SERC School on "*Agricultural Droughts - Aspects of Micrometeorology*" held by CRIDA at ICRISAT.
Kiambi D. 2006. Application of molecular markers in plant breeding. Invited seminar presented at the Agricultural Research Centre, Wad Medani, Sudan on 11th May 2006.
Kumar Rao JVDK and **Gupta B**. 2006. Promotion of rainfed rabi cropping in rice fallows of Chattisgarh. Presented at State-level Workshop on rainfed rabi cropping held by CRS/NABARD at Raipur, 1-2 July 2006.
Kumar Rao JVDK, Harris D, **Mahesh K and Gupta B**. 2006. Promotion of rainfed rabi cropping in rice fallows of eastern India and Nepal – Overview. I. Presented at State-level Workshop on rainfed rabi cropping held by CRS/NABARD at Raipur, 1-2 July 2006.
Mati BM. 2006. NILE_IWRM-Net National training workshop on “the Role of integrated water resources management (IWRM) on ecological conservation” 16-19th October 2006, the IMTR, Nairobi, Kenya.
Mati BM. 2006. Southern Africa Regional Irrigation Association (SARIA) Workshop held in Pretoria, South Africa, 31 January to 1st February 2006.
Mati BM. 2006. The 2nd IFAD Rural Finance thematic workshop. 24th – 26th July 2006, Addis Ababa, Ethiopia.
Mati BM. 2006. The 2nd Regional Workshop on Agricultural Water Management in Eastern and Southern Africa, held in Maputo, Mozambique, 18–22nd September 2006.
Mati BM. 2006. The UNOPS/IFAD Regional Implementation Workshop, held in Blantyre, Malawi, 13th – 17th November 2006.
Mati BM. 2006. The World Water Week, Sockholm, Sweden, 20-27th August 2006
Mati BM. 2006. Workshop on Best Practices and Technologies for Small Scale Agricultural Water

Invited Seminars:

Management in Ethiopia. Addis Ababa, Ethiopia, 7-9th March, 2006.
Monyo ES. 2006. Training of Agricultural Extension Development Officers and Agricultural Extension Development Coordinators of the Ministry of Agriculture (Malawi) from two districts (Salima and Blantyre) on Principals of Seed Production – 17 Aug, 2006.
Monyo ES. 2006. Training of Agricultural Extension Development Officers and Agricultural Extension Development Coordinators of the Ministry of Agriculture (Malawi) from two districts (Salima and Blantyre) on Groundnut origin, classification and adaptation and Management of groundnut disease – 16 Aug, 2006.
NAYAK S, JAYASHREE B, Hoisington DA and Varshney RK. 2006. Current status of DREB ortholog research at ICRISAT. Generation Challenge Programme (GCP) Annual Research Meeting 2006, Sao Paulo, Brazil, September 12-16, 2006.
NAYAK S, JAYASHREE B, Hoisington DA and Varshney RK. 2006. Current status of DREB ortholog research at ICRISAT. Generation Challenge Programme (GCP) Annual Research Meeting 2006, Sao Paulo, Brazil, September 12-16, 2006.
Ntare BR, Rattunde FH, *Kalinganire A., Levasseur V, et Dial, O*. 2006. Articulation entre recherche nationale et recherche internationale : Cas de l'Afrique de l'Ouest. Invited paper presented at the Agricultural Research week in Mali, 5-9 June 2006, Bamako, Mali.
Pande S, SHARMA M, **Urkurkar JS**, **Neupane RK** and **Bakr MA**. 2006. Farmers' participatory integrated crop management with special reference to fungal foliar diseases of vegetable chickpea. Pages 77-78 *in* First International Conference on Indigenous Vegetables and Legumes, December 12-15, 2006, ICRISAT Campus, Patancheru, India.
Pande S. 2006. Genotypic diversity and application of tools of biotechnology for the management of fungal foliar diseases of chickpea in the Indo-Gangetic-plains of India. Pages 65-67 *in* National Symposium on "Biodiversity and biotechnology: research and development needs in edible mushrooms and crop diseases management". 28th Annual meet of Indian Society of Mycology and Plant Pathology Nov 09-11 Nov. 2006. GB Pant University of Agriculture and Technology, Pantnagar- 263-145, Uttranchal, India.
Parthasarathy Rao P, GuravaReddy K, Belum VS Reddy, Gowda CLL, **Rao CLN** and **Bhavaniprasad A** . 2006. Linking Producers and Processors – Sorghum for Poultry Feed: A Case Study from India presented at Regional Consultation on Linking Farmers to Markets: Lessons Learned and Successful Practices. Cairo, Egypt. January 28 to February 2 2006. http://www.globalfoodchainpartnerships.org/cairo
Parthasarathy Rao P. 2006. Linking producers and processor: sorghum and pearl millet for poultry feed in Asia. Paper presented at the Expert Consultation on Agricultural Innovation: Linking Farmers to Market and APAARI General Assembly, 6-8 November 2006, New Delhi, India.
<u>Paterson AH</u>, <u>Bowers JE</u>, <u>Gingle AR</u>, <u>Peterson DG</u>, <u>Kresovich SE</u>, <u>Messing J</u>, Hash CT and <u>Rokhsar DS</u>. 2006. Sequencing of the sorghum genome. Plant & Animal Genome XIV, Jan 14–18 2006, Town & Country Hotel, San Diego, CA, USA. Final Abstracts Guide. W65. http://www.intl-pag.org/14/abstracts/
Piara Singh. 2006. Crop Simulation Models as Decision-Making Tools for Managing Agricultural Droughts. Invited lecture on 04 Oct. 2006 to the participants of the SERC school in "Agricultural droughts – aspects of micrometeorology" held by CRIDA at ICRISAT (Piara Singh and K Srinivas).
Piara Singh. 2006. Seasonal Rainfall Forecasting for the Scarce Rainfall Zone of Andhra Pradesh and Cropping Decisions. Delivered at CRIDA in May 2006 (Piara Singh and V Nageswara Rao).
Piara Singh. 2006. Crop models for crop management using Seasonal forecasting. Invited lecture on the workshop on "Applications of seasonal climate prediction in rainfed agriculture" in May 2006, at ANGRAU, Rajendranagar, Hyderabad (Piara Singh and V Nageswara Rao).
Prabhakar Pathak. 2006. Management of Land and Water Resources for Achieving Food Security in Drylands through Participatory Watershed Management. Delivered a keynote address during a seminar on "Bringing in second green revolution – Dryland farming development through organic farming – methods for water conservation". Organized by Sastriya Vignana Samithi, Kakinada, Andhra Pradesh on 10 September 2006.
Rai KN. 2006. Made presentation on "Forage potential of pearl millet" in the AICPMIP Annual Group Meeting and the National Seminar on "Millets as Food, Fodder and Feed Energy" at Junagarh, Gujarat, India, during 8–14 April 2006.
Rai KN. 2006. Made presentation on "Pearl millet hybrid parents research at ICRISAT" in the seminar on "Challenges before public sector seed companies in the light of genetically modified crops" organized by Maharashtra State Seeds Corporation (MSSC), Akola, Maharashtra, India, during 8–10 December 2006.

Invited Seminars:

Rai KN. 2006. Made presentations on "Adaptation and yield potential of pearl millet for grain and fodder production" to research groups at Program Facilitation Unit (PFU) of the CGIAR, Tashkent; Tashkent State Agricultural Institute; and Samarkand Agricultural Institute, Uzbekistan, during 18 September–3 October 2006.
Rai KN. 2006. Made presentations on "Adaptation and yield potential of pearl millet for grain and fodder production" at INIFAP's research stations at Rio Bravo and Zacatecas, Mexico, during 16–25 August 2006.
Rai KN. 2006. Presented ICRISAT-Private Sector (PS) Hybrid Parents Research Consortia on Sorghum, Pearl Millet and Pigeonpea, to the MSSC Governing Board, Mumbai, India, 4 September 2006.
Rao KPC and Kumara Charyulu D. 2006. Role of Micro-finance Institutions in providing Credit and Insurance Services in Drought Prone Areas of A.P, Invited paper at the National Seminar on Rural Microfinance, Sponsored by UGC and organized by P.G Department of Economics, Sardar Patel University, Vallabh Vidyanagar, Gujarat-388120 from October 17 to18, 2006.
Rao KPC. 2006. Livelihoods, Enterprises and Incomes of villagers in Six Andhra Pradesh villages, Invited paper at the National seminar on 'Model Village' at Mahatma Gandhi National Institute of Research and Social Action (MGNIRSA) on 3rd November, 2006 at Hyderabad.
Rao KPC. 2006. WTO Issues and Suggested Measures to be taken by Government and FAPCCI, Invited paper at the National Seminar on Agriculture and Processed Food Export –Emerging Trends Organised by Federation of Andhra Pradesh Chamber of Commerce and Industry (FAPCCI) and Agricultural and Processed foods Export Development Authority (APEDA), April 22, 2006 at Hyderabad.
Reddy BVS and **Ramesh S**. 2006. Sweet sorghum – a potential alternate raw material for ethanol production – Cultivar options. Presented at the workshop on "Sweet sorghum for improving the livelihood of farmers", 31 March 2006, FAPCCI Bhavan, Red hills, Hyderabad, Organized by Federation of farmers associations, Hyderabad.
Reddy BVS, **Ramesh S**, Parthasarathy Rao P, **Seetharama N** and **Longvah T**. 2006. Sorghum grain micronutrients and β-carotene – Role in the diets and scope for their genetic enhancement. Presented at the workshop on "Crop bio-fortification for alleviating micronutrient malnutrition" at the MS Swaminathan Research Foundation, February 13-14 2006, Chennai, India.
Reddy BVS, **Ramesh S**, Wani SP, *Ortiz R, Ceballos H* and SREEDEVI TK. 2006. Agricultural Research and Energy Security: The Crop Link to Bio-Energy. An invited lead discussion paper presented at Global Forum on Agricultural Research (GFAR) Triennial Conference 2006, 08-11 December, New Delhi, India.
Reddy BVS, **Ramesh S,** Wani SP, *Ortiz R, Hernan C* and SREEDEVI TK. 2006. Agricultural research and energy security – The crop link to bio-energy. An invited lead discussion paper presented at the GFAR Triennial conference, 10th November 2006, New Delhi, India.
Reddy BVS, Sharma HC, Thakur RP, Upadhyaya HD and Vadez V. 2006. ICAR-ICRISAT partnership research on sorghum: synergies. Presented at the Limited SRC for "Genetic improvement in sorghum" meeting, 20 July 2006, NRCS, Hyderabad.
Reddy BVS. 2006. Sweet Sorghum-A promising alternative raw material for ethanol production. An invited lead discussion paper presented at Global Forum on Agricultural Research (GFAR) Triennial Conference 2006, 08-11 December, New Delhi, India.
Rupela OP. 2006. Biological Approaches for Crop Production and Protection. Lead paper, National Conference on Organic Farming. Horticultural Research Station, Tamil Nadu Agricultural University, Ooty, sponsored by the National Horticultural Mission (NHM) of the Ministry of Agriculture, Government of India, 11-18 June 2006.
Rupela OP. 2006. Inputs required for biological approaches of crop production and protection. Lead paper, National Seminar on Standards and Technologies of Non-Conventional Organic Inputs, Project Directorate of Cropping Systems Research (PDCSR), Modipuram, 8-9 April 2006.
Rupela OP. 2006. Low-cost biological approaches for rain-fed crop production system – A seven years case study. Brainstorming dialogue on organic farming, Indian Institute of Sugarcane Research, Lucknow, 02 Feb 2006, organized at the behest of DG-ICAR to take step towards developing 'organic farming policy' for India.
Rupela OP. 2006. Making microorganisms work for crop production and protection. Brainstorming session on role of agriculturally important microorganisms in sustainable food and agriculture production. Organized by the National Bureau of Agriculturally Important Microorganisms (NBAIM), an ICAR institution near Varanasi, Uttar Pradesh, 16 to 18 April 2006.

Invited Seminars:

Rupela OP. 2006. Scope of managing crops without synthetic agro-chemicals. National workshop on Organic Farming (OF), Pune, 30-31 Jan 2006, organized by the National Center for Organic Farming (NCOF), Gaziabad, Ministry of Agriculture, Government of India.
Rupela OP. 2006. Sustaining growth in organic agriculture through partnerships. Theme Paper, National Seminar on Organic Agriculture, Kochi, 20-21 Nov 2006, organized by the College of Agriculture Banking, Reserve Bank of India, Pune, India.
Rupela OP. 2006. Theme paper “Sustaining growth in organic agriculture through partnerships”, National Seminar on Organic Agriculture, Kochi, Kerala 20-21 November 2006, organized by the College of Agricultural Banking of the Reserve Bank of India, Pune in association with Co-operative Banks of three districts of Kerala.
Sandhu JS, Gupta SK, Gaur PM**, Saxena AK, SHARMA S** and **KAUR P. 2006.** Studies on early podding varieties and post-harvest management of immature green grains of chickpea to be used as vegetable. Page 81 *in* Program and Abstracts of First International Conference on Indigenous Vegetables and Legumes, December 12-15, 2006, ICRISAT, Patancheru, Hyderabad, India.
Saxena KB and Gowda CLL. 2006. Evolution of commercial pigeonpea hybrids in India. Paper presented at Golden Jubilee & AE-BRNS Life Sciences Symposium, December 18-20, 2006 at Bhabha Atomic Research Centre, Mumbai, India.
Saxena KB. 2006. Breeding hybrids for enhancing productivity in pigeonpea. Paper presented at meeting organized by Maharashtra State Seed Corporation, Akola, December 8, 2006.
Sharma HC, Clement SL and Ridsdill-Smith TJ. 2006. Exploitation of wild relatives of crops as sources of novel genes for resistance to insect pests *in* Seventieth Biennial International Plant Resistance to Insects Workshop, 9 – 12 April 2006. West Lafayette, Purdue University, Indiana, USA.
Sharma HC, Dhillon MK and Romeis J. 2006. Effect of *Bacillus thuringiensis* cry toxins on survival and development of the *Helicoverpa armigera* larval parasitoid, *Campoletis chlorideae*, and the coccinellid predator, *Cheilomenes sexmaculatus*. Page 273 *in* 9th International Symposium on Biosafety of Genetically Modified Organisms, Biosafety Research and Environmental Risk Assessment, Jeju Island, Korea 24-29 September 2006.
Sharma HC, Dhillon MK and Romies J. 2006. Influence of Cry1Ab and Cry1Ac intoxicated *Helicoverpa armigera* larvae on the survival and development of the parasitoid, *Campoletis chlorideae*. Page 25 *in* Annual Pulse Network Meeting 2-4 February 2006, Indo-Swiss Collaboration in Biotechnology, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., India.
Sharma HC, Dhillon MK, Sharma KK and Hoisington DA. 2006. Bio-safety of transgenic crops to non-target organisms. *In* Economic Consideration of Bio-safety and Biotechnology Regulations in India: A Policy Dialogue? 24-25 August 2006, New Delhi, India. Research and Information Systems (RIS) for Developing Countries, and International Food Policy Research Institute (IFPRI).
Sharma HC. 2006. Applications of biotechnology for pest management: Potential and limitations *in* National Symposium on Biotechnology-food and Nutrition Security, 22 Dec 2006. National Institute of Nutrition (NIN) Scientists Association, Hyderabad, Andhra Pradesh, India.
Sharma HC. 2006. Applications of biotechnology in agriculture: Potential and limitations *in* Golden Jubli Celebrations of Marathwada Agricultural University, 30- 31 Dec 2006. Marathwada Agricultural University, Parbhani, Maharashtra, India.
Sharma HC. 2006. Bio-safety of transgenic crops to non-target organisms. *In* Pre-market Bio-safety and Risk Assessment of GM Crops and GM-derived Products, 13 – 17 Nov 2006. International Center for Genetic Engineering and Biotechnology, New Delhi, India.
Sharma HC. 2006. Genetic diversity in *Helicoverpa armigera* populations and its management in different agro-ecosystems. *In* National Conference on Biodiversity, 12-15 Feb 2006. National Biodiversity Authority, Chennai, Tamil Nadu, India.
Sharma HC. 2006. Host plant resistance to cotton bollworm/legume pod borer, *Helicoverpa armigera. In* Proteomic Insights into Plant-insect Interactions, 12 – 15 Dec 2006. Workshop Under the Max Plank Society – India Partnership Program, National Chemical Laboratory, Pune, Maharashtra, India.

Invited Seminars:

Sharma HC. 2006. Transgenic in pest management. *In* Reporting Biotechnology: Issues and Opportunities for the Telugu/English News Media, 7 - 8 August 2006. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India.
Sharma KK and Karuppanchetty S. 2006. Agri-business incubator at ICRISAT: Opportunities for public-private sector partnerships *in* BioAsia 2006, Hyderabad, February 9-11, 2006.
Sharma KK, **Anjaiah V,** Rai M, **BHATNAGAR M** and Swamy Krishna T. 2006. Genetic Transformation for the biofortification of groundnut and pigeonpea *in* Joint India Biofortification-HarvestPlus meeting on Crop Biofortification for Alleviating Micronutrient Malnutrition. MS Swaminathan Research Foundation (MSSRF). Chennai, India, February, 13-14, 2006.
Sharma KK, **BHATNAGAR-MATHUR P** and VANI G. 2006. Genetic engineering of chickpea for tolerance to drought stress *in* Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, ICRISAT, February 2-4, 2006.
Sharma KK, BHATNAGAR-MATHUR P, **JYOSTNA DEVI M,** VANI G, Vadez V, <u>Verma DPS</u> and <u>YAMAGUCHI-SHINOZAKI, K.</u> 2006. Engineering abiotic stress tolerance in chickpea: Expression of P5CSF*129A* and *At DREB1A* genes increase transpiration efficiency under water limiting conditions *in* Sixth Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, University of Delhi, Delhi, December 2-4, 2006.
Sharma KK, BHATNAGAR-MATHUR P, **Jyotsana DEVI M** and Vadez V. 2006. Drought-resistant crops *in* AsianBio 2006, Biotechnology Opportunities for Developing Countries, Third Asian Biotechnology Conference 2006, Manila, Philippines, November 9-10, 2006
Sharma KK, BHATNAGAR-MATHUR P, SAIVISHNUPRIYA K, Anjaiah V, Vadez V, Waliyar F, Lava Kumar P, Nigam SN and Hoisington DH. 2006. Genetic engineering of groundnut for crop improvement *in* International Conference on Groundnut Aflatoxin Management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Sharma KK, Gowda CLL and Waliyar F. 2006. Public-Private Sector Partnerships: A Case Study of ICRISAT *in* International Conference on "Agriculture for Food, Nutritional Security and Rural Growth, B.P. Pal Centenary Celebration, TERI, New Delhi, 25-27 May 2006.
Sharma KK, Gowda CLL, Waliyar F and Karuppanchetty K. 2006. Public-Private Partnerships & Agri-business potential in India: ICRISAT case study *in* International Conference on Biofuels-The next Generation Sustainable Fuels, CII-Sohrabji Godrej Green Business Centre, Hyderabad, June 29-30, 2006.
Sharma KK, Lava Kumar P, Waliyar F, <u>LAVANYA M,</u> Reddy AS and Swamy Krishna T. 2006. Development and evaluation of transgenic peanuts for induced resistance to the Indian peanut clump virus *in* Symposium on Management of Vector-Borne Viruses, 16th Annual Convention of Indian Virological Society, Feb. 7-10, 2006, ICRISAT, India.
Sharma KK, SAIVISHNUPRIYA K, Arokiasamy S, Lava Kumar P and <u>Beachy R</u> 2006. Development of transgenic groundnut for resistance to the tobacco streak virus *in* ICAR-Cornell Program Meeting. November 23, 2006, IARI, New Delhi
Sharma KK. 2006. Biotechnological approaches for biotic and abiotic stresses in crops of the semi-arid tropics. PennState University, USA, April 11, 2006.
Sharma KK. 2006. Biotechnology for abiotic stress tolerance and enhanced nutrition *in* Panel Discussion on "Biophysical and Socio-economic dimensions of food security in the developing countries. 93rd Indian Science Congress, Acharya N.G. Ranga Agricultural University, Hyderabad, January 3-7, 2006.
Sharma KK. 2006. Biotechnology for sustainable agriculture in the semi-arid tropics *in* International Workshop on Fostering the next green revolution- Role of biotechnology in advancing Indian agriculture. June 2, 2006, ANGRAU, Hyderabad.
Sharma KK. 2006. Current status of transgenics at ICRISAT and future directions. London, ON, Canada, April 17, 2006.
Sharma KK. 2006. Current status of transgenics research at ICRISAT. Bureau of Agricultural Research, Department of Agriculture, Quezon City, Philippines, November 13, 2006.
Sharma KK. 2006. Current status of transgenics research at ICRISAT and Public-Private Partnerships & Agri-business potential. University of Philippines, Los Banos, Philippines, November 14, 2006
Sharma KK. 2006. Genetic Transformation, Crop Improvement & Scientific Advancements: *Status, Issues and Future Directions*. *In* Media Workshop on Reporting Biotechnology: Issues & Opportunities for the

Invited Seminars:

Telugu/English News Media, ISAAA-ICRISAT, Patancheru, August 708, 2006.
Sharma KK. 2006. ICRISAT and Current status of transgenics at ICRISAT. University of Wisconsin, April 15, 2006.
Sharma KK. 2006. Public-Private Partnerships & Agri-business potential: ICRISAT Case Study *in* International Conference on Public Private Partnership in Agri Infrastructure, Confederation of Indian Industry (CII), December 1-4, 2006
Sharma KK. 2006. Public-Private Partnerships: A Case Study of ICRISAT. Bureau of Agricultural Research, Department of Agriculture, Quezon City, Philippines, November 13, 2006.
Sharma KK. 2006. Role of science & technology in private public partnership for sustainable & inclusive rural development: Panel discussant *in* CII-ICRISAT Workshop on "Corporate and Science & Technology Institutions Partnership for inclusive and sustainable development and economic growth. ICRISAT, February 27, 2006.
Sharma KK. 2006. Status of transgenic technology for sustainable agriculture in the semi-arid tropics *in* Beyond Bt Cotton- the promise of Agri-biotechnology, Bangalore Bio 2006, Bangalore, June 7-9 2006.
Sharma KK. 2006. Transgenic biofortification of groundnut and pigeonpea:Product Concept, HarvestPlus Workshop, IFPRI, USA, April 6, 2006.
Sharma KK. 2006. Transgenic Crops: *Applications and status of commercialization*. Workshop on Biosafety regulations for transgenic crops and the need for harmonizing them in the Asia-Pacific region, APCoAB-ICRISAT, Patancheru, July 31-August 2, 2006.
Sharma KK. 2006. Water, Water Everywhere and Not a Drop for Crops-Drought Panel Review *in* BIO 2006 Food and Agriculture Track, Plant Biotechnology: Gene Technology and Abiotic Stress Tolerance. Chicago, USA, April 13, 2006.
Shiferaw B and Jones R. 2006. Enhanced partnerships to support technology scaling up and out: development of effective seed supply systems. Presented at the Ethiopian Institute of Agricultural Research (EIAR), 9-11 May, Addis Ababa, Ethiopia.
Shiferaw B and **Obare G.** 2006. ICRISAT Regional Program on Markets, Policies and Institutions. Presented at the Improving Market Access for Drylands Commodities. Regional Policy Workshop 26-28 April 2006 Drylands Development Centre, United Nations Development Programme (UNDP), Nairobi, Kenya.
Shiferaw B. 2006. Poverty traps and development pathways in the semi-arid areas. Oral presentation at the Consultation Seminar on World Development Report 2008. Invited by ILRI in Nairobi, Kenya, November 13-14 2006.
Singh AK and Upadhyaya HD. 2006. ICAR – ICRISAT Partnership Projects – Genetic Resources. ICRISAT Partnership Projects Meeting, 25-26 May 2006, New Delhi, India.
Singh NK, Varshney RK, Hoisington DA, **Datta S**, **Kurvinashetty M**, **Singh MN** and **Wanjari K.** 2006. In Pigeonpea genomics initiative: Introduction. Application of genomics to chickpea, pigeonpea, and peanut improvement. An International Workshop March 6-9, 2006, ICRISAT, Patancheru, Andhra Pradesh 502 324, India.
Sreedevi TK. 2006. 93rd Indian Science Congress on 6 January 2006 at ANGRAU, Hyderabad
Sreedevi TK. 2006. International Conference on Biofuels-" The Next Generation sustainable Fuels" during 29 & 30 June, 2006, CII – Godrej GBC, Hyderabad
Turner MD, *Ayantunde AA.*, Patterson ED and PATTERSON KP. 2006. Farmer-herder relation and conflict management in agro-pastoral zone of Niger. Paper presented at International Conference on the Future of Transhumance Pastoralism in West and Central Africa. 21-25 November, 2006, Abuja, Nigeria. National Animal Production Research Institute, Ahmadu Bello University, Zaria, Nigeria.
Twomlow S, Rohrbach D, Hove L, Mupangwa W, MASHINGAIDZE N, Moyo M, Chiroro C and MAPHOSA. 2006. Is conservation agriculture an option for vulnerable households? Lessons from Humanitarian relief in Zimbabwe. Paper Presented at African Conservation side meeting, Summit on Food Security In Africa Availability, Accessibility and Affordability 4 -7 December, 2006.
Twomlow S. 2006. Strengthening Impacts from Soil Fertility Management Research in Zimbabwe: Precision Input Systems For Drought Prone Areas. CGIAR Partnerships and Impacts in Zimbabwe. 26th July 2006. Presentation to the Government of Zimbabwe.

Invited Seminars:

Twomlow S. 2006. Relief Programs and Technology Promotion – ICRISAT and WATERnet, CP17 in Zimbabwe. Power Point Presentation 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process'. Lilongwe, Malawi, 1-3 Septmber 2006.
Twomlow S. 2006. Dryland Smallholder Farming in Southern Africa – Opportunities to improve water use efficiency. Power Point Presentation to 2nd Workshop on Agricultural Water Management in Eastern and Southern Africa 'Water for the Millenuem Development Goal Poverty and Hunger'. 18-22 September, 2006, Maputo, Mozambique.
Upadhyaya HD and **BRIGITTE LALIBERTÊ**. 2006. Development of Conservation Strategies. Developing a Strategy for the Global conservation of Pigeonpea Genetic resources. 23-24 August 2006, ICRISAT, Patancheru, India.
Upadhyaya HD and Gowda CLL. 2006. Germplasm and Genomics: Challenges and Opportunities. Genomics 2006 Challenges & Opportunities. 28 March 2006, NBPGR, New Delhi, India.
Upadhyaya HD and Reddy KN. 2006. Pearl millet germplasm collection, conservation, characterization and utilization in crop improvement. Training course on pearl millet improvement and seed production, 2-15 December 2006, ICRISAT, Patancheru, India.
Upadhyaya HD, Gowda CLL and Sastry DVSSR. 2006. Crop germplasm assembly, regeneration, conservation and utilization. Training of Trainers for Productivity Enhancement in Integrated Watershed Management, 6-16 November 2006, ICRISAT, Patancheru, India.
Upadhyaya HD, BHATTACHARJEE R, Dwivedi SL, Gowda CLL, Hash CT, HAUSSMANN B, Kashiwagi J, Pande S, Kumar PL, Gaur PM, Pundir RPS, *Udupa SM, Baum M, FURMAN BJ* and *Valkoun J*. 2006. Challenges for Characterizing and Utilizing Legume Germplasm. Application of Genomics to Chickpea, Pigeonpea, and Peanut Improvement, March 6-9, 2006, ICRISAT, Patancheru, India.
Upadhyaya HD, BHATTACHARJEE R, Dwivedi SL, Gowda CLL, Hash CT, HAUSSMANN B, Kashiwagi J, Pande S, Kumar PL and Pundir RPS. 2006. Sustainable Biodiversity of Sorghum, Pearl millet, Small millets, Groundnut, Chickpea, and Pigeonpea for Current and Future Generations. Global Inhouse Review. February 2006, ICRISAT, Patancheru, India.
Upadhyaya HD, Dwivedi SL, Hoisington DA, Gaur PM, Varshney RK, Gowda, CLL, Chandra S, Singh S, Baum M, Udupa SM and Furman BJ. 2006. Genotyping chickpea composite collection. Paper presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Dwivedi SL, Hoisington DA, Gaur PM, Varshney RK, Gowda, CLL, Chandra S, Singh S, Baum M, Udupa SM and Furman BJ. 2006. Genotyping chickpea composite collection. Paper presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Gowda CLL and Hanumanth Rao B. 2006. Plant Genetic Resources management at ICRISAT, Germplasm Sharing and Related IPR Issues. Workshop on Biodiversity, PVP, and IPR Protection in India, 2 March 2006, NRCS Rajendranagar, Hyderabad, India.
Upadhyaya HD, Gowda CLL and Sastry DVSSR. 2006. Crop Germplasm Assembly, Regeneration, Conservation, and Utilization. Training Program on Scalling Out the benefits of Productivity Enhancement Initiatives of Intergrated Watershed Development, 24 April – 3 May 2006, ICRISAT, Patancheru, India.
Upadhyaya HD, Gowda CLL and Sastry DVSSR. 2006. Plant Genetic Resources Management: collection, characterization, conservation and utilization. Learning Program on Crop Improvement, Genetic Resources and Seed Systems with focus on legumes for Participants from Uzbekistan, 7-18 November 2006, ICRISAT, Patancheru.
Upadhyaya HD, Gowda CLL, BHATTACHARJEE R, Murthi AN and **Singh L**. 2006. Pigeonpea Germplasm_Global Perspectives. Developing a Strategy for the Global conservation of Pigeonpea Genetic resources. 23-24 August 2006, ICRISAT, Patancheru, India.
Upadhyaya HD. 2006. Genetic Diversity for Crop Improvement. Inter Center Genetic, Engineering and Biotechnology Group Meeting, 5 October 2006, ICRISAT, Patancheru, India.
Vadez V, **DEVI JM,** BHATNAGAR-MATHUR P, *Serraj R.* and Sharma KK. 2006. Evaluation and deployment of transgenic drought-tolerant groundnut at ICRISAT *in* GCP sub-programme commissioned research project SP3-19 (2005-2006), Sept., 2006, Mexico.
Vadez V, Hash CT, Rizvi SMH, Bidinger FR, **Bantte K**, Sharma KK, JYOTSNA DEVI J, BHATNAGAR-MATHUR P, Kashiwagi J, Krishnamurthy L, Hoisington D, Varshney RK, Gaur PM, Nigam SN, ARUNA R and Upadhyaya HD. 2006. What is the scope for molecular breeding and genetic engineering to improve crops' drought tolerance? Proceeding of the 4th Biovision Conference, Alexandria 26-29 April 2006.

Invited Seminars:

Vadez V, Hash CT, Rizvi SMH, Bidinger FR, **Banttee K**, Sharma KK, DEVI MJ, BHATNAGAR-MATHUR P, Kashiwagi J, Krishnamurthy L, Hoisington D, Varshney RK, Gaur PM, Nigam SN, ARUNA R and Upadhyaya HD. 2006. What is the scope for molecular breeding and genetic engineering to improve crops' drought tolerance? Proceeding of the 4th Biovision Conference, Alexandria 26-29 April 2006.
Vadez V, Hoisington DA, Upadhyaya HD, Hash CT, Varshney RK, Gaur PM and Nigam S. 2006. Conventional and Molecular approaches to assess abiotic stress tolerance. Annual Planning and Review Meeting, AVRDC Headquarter, Kao Siung, Taiwan, 20-22 November 2006.
Vadez V, Krishnamurthy L, Gaur PM, Upadhyaya HD, Hoisington DA and Varshney RK**.** 2006. Genetic variability for salinity tolerance in chickpea. Paper presented in the 3rd International Conference on Legume Genomics & Genetics held in Brisbane, Australia on 9-13 April 2006.
Vadez V, Krishnamurthy L, Gaur PM, Upadhyaya HD, Hoisington DA, Varshney RK, <u>Turner NC</u>, and <u>Siddique KHM</u>. 2006. Tapping the large genetic variability for salinity tolerance in chickpea. In Proceedings of 13th Australian Society of Agronomy Conference, 10-14 September 2006, Perth, Australia. http://www.regional.org.au/au/asa/2006/concurrent/environment/4561_vadez.htm.
Varshney RK and Hoisington DA. 2006. Functional molecular markers for plant breeding *in* National Training Course on "Molecular markers and transgenics for precision in breeding", Directorate of Rice Research (DRR), Hyderabad, India, March 20-29, 2006.
Varshney RK and Hoisington DA. 2006. Genomics strategies for crop improvement in semi-arid tropics: introduction and prospects. Vavilov Seminar, Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben, Germany, January 20, 2006.
Varshney RK and Hoisington DA. 2006. International agricultural research centre on genomics and plant breeding. In: Using Molecular Markers for Improving the Efficiency of Plant Breeding in Sri Lanka, Sri Lanka Council of Agricultural Research Policy, University of Colombo, Sri Lanka, December 6-8, 2006 (presentation was sent by mail).
Varshney RK, Hash CT and Hoisington DA. 2006. Applied genomics research at ICRISAT. International Center for Genetic, Engineering and Biotechnology (ICGEB) Group Meeting, 5 October 2006, ICRISAT, Patancheru, India.
Varshney RK, Hoisington D, Upadhyaya HD, Vadez V, Gaur PM, Dwivedi S, ARUNA R, Kashiwagi J, BHATTACHARJEE R, Nigam SN, BALAJI J and Chandra S. 2006. Improvement of water-stress tolerance in chickpea and peanut: applications and potential of genomic and physiological approaches. IX European Society for Agronomy Congress, Warsaw, Poland, September 4-7, 2006.
Varshney RK, Hoisington DA and <u>Graner A.</u> 2006. Functional molecular markers for plant breeding. University of Agricultural Sciences, Dharwad, India, May 12, 2006.
Varshney RK, Hoisington DA and <u>Graner A.</u> 2006. Genomic strategies for studying drought tolerance: results from barley and applications to crops in the semi-arid tropics. Plenary lecture in International Symposium on Frontiers in Genetics and Biotechnology- Retrospect and Prospect, Osmania University, Hyderabad, India, January 8-10, 2006.
Varshney RK, Hoisington DA and <u>Graner A.</u> 2006. Genomics-assisted breeding for crop improvement. In: National Training Programme on Methods in Molecular Ecology", Centre for DNA Fingerprinting and Diagnostics (CDFD), Hyderabad, India, September 18-30, 2006.
Varshney RK, Hoisington DA and <u>Graner A.</u> 2006**.** Genomics-assisted breeding for crop improvement. In: Using Molecular Markers for Improving the Efficiency of Plant Breeding in Sri Lanka, Sri Lanka Council of Agricultural Research Policy, University of Colombo, Sri Lanka, December 6-8, 2006 (presentation was sent by mail).
Varshney RK, Hoisington DA and JAYASHREE B. 2006. Progress on identification of orthologous candidate gene sets for DREB1A and DREB2a at ICRISAT**.** ADOC Workshop, CIRAD Montpellier, France, March 20-22, 2006.

Invited Seminars:

Varshney RK, Hoisington DA, Saxena KB, Upadhyaya HD, JAYASHREE B and MALLIKARJUNA N. 2006. Pigeonpea genomics research at ICRISAT. National Research Centre on Plant Biotechnology (NRCPB), IARI, New Delhi, India, November 10, 2006.
Varshney RK, Hoisington DA, Upadhyaya HD, Vadez V, Gaur PM, ARUNA R, Kashiwagi J, BHATTACHARJEE R, Nigam SN, BALAJI J, Saxena KB and Chandra S. 2006. Genomics approaches to enhance molecular breeding strategies in legume crops of the semi-arid tropics. National Symposium on Tends in Research and Technologies in Agriculture and Food Sciences, December 18-20 2006 Bhabha Atomic Research Centre Golden Jubilee & DAE-BRNS, Mumbai, India..
Varshney RK. 2006. Molecular markers and marker assisted selection in crop plants. National Academy of Sciences of India (NASI), Allahabad, India, July 27, 2006.
Varshney RK. 2006. Conserved orthologous set of markers in legumes. Generation Challenge Programme (GCP) Annual Research Meeting 2006, Sao Paulo, Brazil, September 12-16, 2006
Varshney RK. 2006. Conserved orthologous set of markers in legumes. Generation Challenge Programme (GCP) Annual Research Meeting 2006, Sao Paulo, Brazil, September 12-16, 2006
Varshney RK. 2006. Genomics Assisted Breeding Workshop, Plant and Animal Genome Conference, San Diego, USA.
Varshney RK. 2006. Molecular markers for marker-assisted breeding. Indian National Science Academy (INSA), New Delhi, India, April 13, 2006.
Waliyar F, Lava Kumar P, Nigam SN, Sharma KK, ARUNA R, Hoisington D and Gowda CLL. 2006. Strategies for the management of aflatoxin contamination in groundnut *in* International Conference on Groundnut Aflatoxin Management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Waliyar F, Lava Kumar P, Sharma KK, Nigam SN and Hoisington D. 2006. Integrated multidisciplinary approach for containing aflatoxin-linked malnutrition in humans and animals *in* Intl Conf. Biotechnology Approaches for Alleviating Malnutrition and Human Health. Univ. Agric. Sci., Bangalore, January 9-11, 2006.
Wani SP, SREEDEVI TK and Reddy BVS. 2006. Biofuels: Status, issues and approaches for harnessing the potential – Paper presented at the international conference on The next generation fuels organized by Sohrabji Godrej Green Business Centre and the Confederation of Indian Industry (CII), 29 to 30 June 2006, Hyderabad.
Wani SP. 2006. "Greater Mekong Subregion (GMS): Fourth Meeting of the Working Group on Agriculture (WGA-4) Angkor Palace Resort and Spa, at Siem Reap, Cambodia
Wani SP. 2006. 93rd Indian Science Congress on 6 January 2006 at ANGRAU, Hyderabad
Wani SP. 2006. Intl. Multi-sectoral Joint Conference on Multifunctionality of Sustainable Agriculture and Mitigating Land Degradation and Deforestation for Improved Food Security, Livelihood and Biodiversity at Manila, Phillippines during 28 Nov-1 Dec 2006

Manuals:

Diouf A and Pasternak D. 2006. Illustrated Vegetables manual
Diouf A and Pasternak D. 2006. Illustrated Vegetables Nursery manual
MATI B. 2006. IMAWESA Stakeholder Partnerships, Learning Needs, and Baselines for Project M& E. Report of a Baseline Assessment. SWMnet Working Paper 12.pp36.
MATI BM. 2006. IMAWESA Stakeholder Directory. SWMnet publication, pp 40.
Ndjeunga J, BANTILAN MCS, Rao KPC and Ntare BR. 2006. Impact Assessment of Agricultural Technologies in West Africa. Technical Notes & Exercises. Training Workshop on Impact Assessment of Agricultural Technologies in West Africa, Bamako-Mali. BP 320, Bamako, Mali: International Crops Research Institute for the Semi- Arid Tropics. 48 pp.
Nikiema A and Pasternak D. 2006. Illustrtated Tree Nursery Manual
Pande S, Rao JN and SHARMA M. 2006. Progress Report of Legumes Pathology, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.
Rao Y Mohan, Ravichand K and Rao KPC. 2006. Developed the VLS Documentation Manual for the second generation Village Level Studies (2001-04).
Rao KPC, Njogu A and **Ndegwa WG**. 2006. Assessing Climate Variability and its Effects on Agricultural and Natural Resource management with Advanced Tools and techniques. Training manual, Making the Best of Climate, University of Nairobi, pp81
Saxena, K.B. 2006. Hybrid pigeonpea seed production manual. Patancheru 502 324, Andhra Pradesh, India. International Crops Research Institute for the Semi-Arid Tropics. 32 pp.
Tilly M and Pasternak D.. 2006. Illustrated Fruit Trees Manual.

Policy Briefs:

Rodomiro Ortiz, Crouch JH, Masa Iwanaga, Ken Sayre, Marilyn Warburton, Jose Luis Araus, John Dixon, Martin Bohn, Reddy BVS, **Ramesh S** and Wani SP. 2006. Bioenergy and agricultural research for development. Brief 7 of 12 in Bioenergy and agriculture: promises and challenges (Peter Hazell and Pachauri RK eds), International Food Policy Research Institute, Washington DC, USA and The energy and resources institute, New delhi, India.
Jones RB. 2006. Briefing note on seed trade harmonization for COMESA
Hove L. 2006. Agricultural technology transfer under relief and recovery programs in Zimbabwe: are NGOs meeting the challenge?
Mazvimavi K and Rohrbach D. 2006. “Quantifying Vulnerability – Accurately Reaching Those Who Are Most in Need” ICRISAT Briefing Note No. 5. ICRISAT Bulawayo.
Rohrbach D and Mazvimavi K. 2006. “Do Seed Fairs Improve Food Security and Strengthen Rural Markets?” ICRISAT Briefing Note No. *3*. ICRISAT Bulawayo.
Mazvimavi K, Rohrbach D, Twomlow S and Hove L. 2006. “Building Sustainable Fertilizer Delivery Systems for Drought-Prone Regions” ICRISAT Briefing Note No. 2. ICRISAT Bulawayo.
Parthasarathy Rao P, **Birthal PS** and **Joshi PK**. 2006. Sustaining growth in high value food commodities. role of urbanization and infrastructure. Policy Brief No. 9. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India.
Rao KPC, <u>Xavier Gine,</u> <u>Donald Larson</u>, BANTILAN MCS and Kumara Charyulu D. 2006. How can rainfall insurance help dryland farmers? Policy Brief-7, GT-IMPI, ICRISAT.
Rao KPC, Mohan Rao Y, Chopde VK and Kumara Charyulu D. 2006. How do the farmers in SAT Struggle to Survive?, Policy Brief -10, GT-IMPI, ICRISAT.
Obare G, Shiferaw B and Muricho G. 2006. Leveraging Rural Institutions for Collective Action to Improve Markets for the Poor: Lessons and Policy Options. Policy Brief N. 8. ICRISAT, Patancheru, India.
Twomlow S and Hove L. 2006. Is conservation agriculture and option for vulnerable households?

Varietal descriptor:

Wani SP and Kashiwagi J. 2006. Survey Report for Japan Bank for International Cooperation. Guideline for Implementation of Service on Agriculture of Andhra Pradesh, India. Pages 1-70.

News Articles/Newsletter:

Ananda Vadivelu G, Wani SP**, Bhole LM**, Pathak P and **Pande AB**. 2006. An Empirical Analysis of the Relationship between Land Size, Ownership, and Soybean Productivity-New Evidence from the Semi-Arid Tropical Region in Madhya Pradesh, India.
Andre F van Rooyen. 2006. A home where the buffalo roam? SATrends Issue 64, March 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/mar2006.htm.
ARUNA R and Nigam SN. 2006. Asha - a money spinner in Anantapur. SATrends Issue 70, September 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT). http://intranet/satrends/sep2006.htm.
Ashok S Alur, Ravinder Reddy Ch, Belum VS Reddy, Gowda CLL, Rai KN and Parthasarathy Rao P. 2006. Enhanced utilization of sorghum and pearl millet grain in poultry feed industry to improve the livelihoods of small-scale farmers in Asia. www.Commoditiy India .com. Comprehensiv Agri-commodity Intelligence 6(12):7-13.
Bekele A Shiferaw, **Ratna Reddy V**, Wani SP and Nageswara Rao GD. 2006. Watershed Management and Farmer Conservation Investments in the Semi-Arid Tropics of India: Analysis of Determinants of Resource Use Decisions and Land Productivity Benefits.
Belder P. 2006. "Great in Theory, Not So Good in Practice", SATrends Issue 73, December 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/dec2006.htm.
Bidinger FR, *Blümmel M* and Hash CT. 2006. Response to recurrent selection for stover feeding value in pearl millet variety ICMV 221. International Sorghum and Millets Newsletter 47:113–116.
Dar WD and Bantilan, Cynthia. 2006. Science with a human face, Survey of Indian Agriculture 2006:171-173.
Devilliers S. 2006. BecA Beckons. SATrends Issue 71, October 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/oct2006.htm.
Dimes J. 2006. Partners foster fertilizer use. SATrends Issue 63, February 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/feb2006.htm.
Dimes JP. 2006. Private Partnerships to Increase Fertilizer Use in Africa. Appropriate Technology.
E D'Silva, Wani SP and **Nagnath B**. 2006. The Making of New Powerguda - Community Empowerment and New Technologies Transform a Problem Village in Andhra Pradesh.
Gérard B. 2006. Une recherche-action pour aider les agro-pasteurs sahéliens à prendre leurs décisions. Published in Dimension 3. Journal of Belgian Cooperation. November-December 2006.
Hanumanth Rao B. 2006. The artful lodger! SATrends Issue 63, February 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/feb2006.htm.
Hash CT, *Blümmel M* and Bidinger FR. 2006. Genotype × environment interactions in food-feed traits in pearl millet cultivars. International Sorghum and Millets Newsletter 47:153–157.
Hash CT, Thakur RP, Rao VP and Bhasker Raj AG. 2006. Evidence for enhanced resistance to diverse isolates of pearl millet downy mildew through gene pyramiding. International Sorghum and Millets Newsletter 47:134–138.
Hatibu N. 2006. Pooling to ponder the power of water. SATrends Issue 71, October 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/oct2006.htm.
HOMANN S. 2006. Online publication, ALIVE/LEAD e-conference on "Pastoral mobility and drought management". November 2006. (available at http://www.virtualcentre.org/en/ele/econf_03_alive/policy.htm)
HOMANN S and RISCHKOWSKY B. 2006. Online publication, FUTURE AGRICULTURES e-discussion on "Too many people, too few livestock: pastoralism in crisis?". December 2006. (available at http:// www.future-agricultures.org/pastoralism_responses.html)
HOMANN S. 2006. Goat marketing and technology change. Online publication, Agricultural Coordination Working Group, ACWG Journal, June 2006. (available at http:// www.zimrelief.info).
HOMANN, S. Crops, livestock and livelihoods in Zimbabwe. SATrends Issue 64, March 2006 International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra

News Articles/Newsletter:

Pradesh, India. http://intranet/satrends/mar2006.htm.
Jones RB. 2006. Final communiqués distributed after business plan development workshops – see Excel for details.
Joshi PK, VASUDHA PANGARE, Shiferaw B, Wani SP, BOUMA J and Scott C. 2006. Socioeconomic and Policy Research on Watershed Management in India - Synthesis of Past Experiences and Needs for Future Research.
Kiambi D. 2006. A Sally into Sudan. SATrends Issue 72, November 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/nov2006.htm.
Kiambi D. 2006. Strangulating the *Striga* scourge. SATrends Issue 73, December 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/dec2006.htm.
Koala S. 2006. Calling combatants against desertification. SATrends Issue 68, July 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/july2006.htm.
LOEFFEN MA and Ndjeunga J. 2006. Where have all the pebbles gone? SATrends Issue 72, November 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. ***http://intranet/satrends/nov2006.htm*. **
Mati BM. 2006. Policy-Round Table Meeting plans Strategies for Managing Water for Agriculture in Eastern and Southern Africa: A brief from the Maputo Conference – By: Bancy Mati. Kenya Engineer.
MGONJA MA and ALUMIRA JD. 2006. Crop Water Technology and Markets. Water and Food Monthly (April, May and June 2006).
MGONJA MA, **Mharapara I**, **Pambirei N** and **Takawira M**. 2006. Action speaks louder than words. Field day for the Challenge Program water for Food Project 1 on: Integrated crop varieties, soil fertility and water management technologies linked to Market. Field day at Chikombedzi Zimbabwe April 2006 . SATrends Issue 65, April 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/apr2006.htm.
MGONJA MA, *Waddington SW,* **Hatibu N** and As KM. 2006. Where is the water running? Theme 2 of Challenge Program Water for Food.
Modi P. 2006. Fighting felons with firewalls. SATrends Issue 67, June 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/june2006.htm.
NAGAVALLEMMA KP, Wani SP, **Stephane Lacroix**, PADMAJA VV, VINEELA C, *Babu Rao M* and Sahrawat KL. 2006. Vermicomposting: Recycling Wastes into Valuable Organic Fertilizer.
Nageswararao V. 2006. The power of predictions and probabilities. SATrends Issue 67, June 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/june2006.htm.
NALINI MALLIKARJUNA, 2006. Jaguars, giraffes and g'nuts!. SATrends Issue 67, June 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/june2006.htm.
NALINI MALLIKARJUNA. 2006. If in trouble, go wild!. SATrends Issue 64, March 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/mar2006.htm.
Ntare BR. 2006. Partnership paves the way in Mali: ICRISAT and the Institut d'Economie Rurale jointly spell success in Mali. SATrends Issue 69, August 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India.. **http://www.icrisat.org/satrends/aug2006.htm**
PADMAJA KV, Wani SP, *Lav Agarwal* and Sahrawat KL. 2006. Economic assessment of desilted sediment in terms of plant nutrients equivalent: A case study in the Medak district of Andhra Pradesh.
Pande S. 2006. Flower Power, SATrends Issue 65, April 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/apr2006.htm.
Pande S. 2006. Working from the ground up. SATrends Issue 66, May 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India.

News Articles/Newsletter:

http://intranet/satrends/may2006.htm.
Parthasarathy Rao P and Reddy BVS. 2006. Sorghum - nutrition for the needy. SAT Trends Issue 69, August 2006. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/aug2006.htm.
Parthasarathy Rao P and Rai KN. 2006. Pearl millet a blessing in disguise. .SATrends Issue 70, September 2006. International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India.
Pasternak D and Wani SP. 2006. Fruitful beginnings. SATrends Issue 72, November 2006. International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/nov2006.htm.
Piara Singh. 2006. Leaping over the legume yield gap - SATrends Issue 63, February 2006. International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/feb2006.htm.
Prabhakar Pathak. 2006. New structures recharge groundwater. SATrends Issue 62, January 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/jan2006.htm.
Rangarao GV. 2006. Neem: the bitter truth. SATrends Issue 67, June 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/june2006.htm.
Rangarao GV. 2006. Redheads beware. SATrends Issue 64, March 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/mar2006.htm.
Rattunde F. 2006. Micronutrients against malnutrition. SATrends Issue 73, December 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/dec2006.htm.
Ravishankar K, Prasad N and Nagaraj I. 2006. ICRISAT launches agro-ecotourism complex. SATrends Issue 70, September 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/sep2006.htm.
Reddy BVS and **Ramesh S**. 2006. Sorghum with muscle, SATrends Issue 64, March 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/mar2006.htm.
Reddy V Ratna and **Galab S**. 2006. "Agrarian Crisis: Looking Beyond the Debt Trap", Economic and Political Weekly, Vol. XLI, No. 19, May 13-19, pp.1838-40.
Reddy V Ratna. 2006. "Getting the Implementation Right: Can the Proposed Watershed Guidelines Help?", Economic and Political weekly, Vol. XLI, No. 40, October 7-13, pp. 4292-4295.
Reddy V Ratna. 2006. "'Jalayagnam' and Bridging the Regional Disparities: Irrigation Development and Distribution in Andhra Pradesh", Economic and Political weekly, Vol. XLI, Nos. 43 and 44, November 4, pp. 4613-4620.
SAIVISHNUPRIYA K, **Arockiasamy S**, Lava Kumar P and Sharma KK. 2006. Engineering Resistance to Combat Stem Necrosis Disease of Groundnut: New Hope to Save Groundnut from *Tobacco streak virus* Menace India. ABSPII Newsletter, Vol.1: No. 4 (July 2006).
SAIVISHNUPRIYA K, Arokiasamy S, Kumar PL and Sharma KK. 2006. Engineering resistance to combat stem necrosis disease of groundnut: New hope to save groundnut from *Tobacco streak virus* menace in India. Agriculture Biotech Support Programme II (South Asia) Newsletter 1:2-3.
Saxena KB. 2006. Recipe for hybrid pigeonpea. SATrends Issue 68, July 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/july2006.htm.
Shambu Prasad C, Hall AJ and Wani SP. 2006. Institutional History of Watershed Research: The Evolution of ICRISAT's Work on Natural Resources in India.
Shambu Prasad C, LAXMI T and Wani SP. 2006. Institutional Learning and Change (ILAC) at ICRISAT: A Case Study of the Tata-ICRISAT Project.
Shapiro BI. 2006. Desert Dike. SATrends Issue 63, February 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/feb2006.htm.

News Articles/Newsletter:

Shapiro B. 2006. Niamey Declaration: From Desert to Oasis. SATrends Issue 71, October 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/oct2006.htm.
Sharma HC and Dhillon MK. 2006. Let them eat the cake: Finding alternative hosts for the potentially deprived natural enemy. SATrends Issue 66, May 2006. . International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/may2006.htm.
Sharma KK and Vadez V. 2006. DREB1A holds water, helps overcome drought. SAT trends Issue 62, Janaury 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/jan2006.htm.
Shiferaw B. 2006. Securing Rewards from Raising Pigeonpea. ESA Annual Report 2006. ICRISAT, Nairobi.
Shiferaw B, ANUPAMA GV, Nageswara Rao GD and Wani SP. 2006. Socioeconomic Characterization and analysis of resource-use patterns in Community Watersheds in Semi-Arid India.
Shiferaw BA, Wani SP and Nageswara Rao GD. 2006. Irrigation Investments and Groundwater Depletion in Indian Semi-Arid Villages:The Effect of Alternative Water Pricing Regimes.
Sreenath Dixit. 2006. Space bridges expert-farmer gap. SATrends Issue 62, January 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/jan2006.htm.
Sreenath Dixit, Tewari JC, Wani SP, VINEELA C, **Chourasia AK** and **Panchal HB**. 2006. Participatory Biodiversity Assessment: Enabling Rural Poor for Better Natural Resource Management.
Sreenath Dixit and Wani SP. 2006. Integrated Watershed Management through Consortium Approach.
Sreenath Dixit, Wani SP, Ravinder Reddy Ch, **Somnath Roy**, Reddy BVS, SREEDEVI TK, **Chourasia AK**, Pathak P, **Rama Rao M** and *Ramakrishna A*. 2006. Participatory Varietal Selection and Village Seed Banks for Self-Reliance : Lessons Learnt.
Srinivas S. 2006. Volumes from the virtual vault. SATrends Issue 68, July 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/july2006.htm.
Thakur RP. 2006. Downy mildew on summer pearl millet hybrids- a warning. SATrends Issue 69, Auguat 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/aug2006.htm.
Twomlow S. 2006. New Partnerships boost impact from agricultural relief programmes. Landwards (IAgrE Journal), Winter 2006. 61(4):2-5.
Upadhyaya HD. 2006. Improving pigeonpea with the wild. 2006. SATrends Issue 62, January 2006. International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/jan2006.htm.
Waliyar F and Kumar PL. 2006. An aflatoxin check for humans. SATrends Issue 71, October 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/oct2006.htm.
Wani SP. 2006. "Watershed Plus" Incomes. SATrends Issue 65, April 2006. International Crops Research Institute for the Semi-Arid Tropics Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/apr2006.htm.
Wani SP, Dwivedi RS, **Ramana KV**, **Vadivelu A**, **Navalgund RR** and **Pande AB**. 2006. Spatial Distribution of Rainy Season Fallows in Madhya Pradesh: Potential for Increasing Productivity and Minimizing Land Degradation.
Wani SP, **Singh HP**, SREEDEVI TK, Pathak P, Rego TJ, Shiferaw B and IYER SR. 2006. Farmer-Participatory Integrated Watershed Management: Adarsha Watershed, Kothapally India - An Innovative and Upscalable Approach.
Wani SP and Shiferaw B. 2006. Baseline Characterization of Benchmark Watersheds in India, Thailand and Vietnam.
Winslow M. 2006. A new "Oasis" on the horizon. SATrends Issue 66, May 2006. International Crops Research Institute for Semi Arid Tropics (ICRISAT), Patancheru 502324, Andhra Pradesh, India. http://intranet/satrends/may2006.htm.

Poster Papers:

Alexander G, **Ki KS,** Saxena KB, Khan AA, Ravi D, Vellaikumar S and Blümmel M. 2006. Forage quality in five cultivars of pigeonpea at various stages of maturity when fed to sheep. Page 12 *in* Technological Interventions in Animal Nutrition for Rural Prosperity: Volume I Abstracts (Bakshi MPS and Wadhwa M, eds.). Proceedings of XIIth Animal Nutrition Conference, January 7-9, 2006, College of Veterinary Science and Animal Husbandry, Anand Agricultural University, Anand, India.
Alexander G, **Ki KS,** Saxena KB, Prasad KVSV, HANSON J and Blümmel. M. 2006. Prediction of condensed tannins in pigeonpea forages by near infrared reflectance spectroscopy. Page 153 *in* Strengthening Animal Nutrition Research for Food Security, Environment Protection and Poverty Alleviation: Abstract papers (Pattanaik AK, Narayan Dutta and Verma AK, eds.). Proceedings of VIth Animal Nutrition Association Biennial Conference, September 15-17, 2006, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, India.
Anand Babu, BANTILAN, MCS, ANUPAMA GV, DEEPTHI H and PADMAJA R. 2006. Dryland agriculture: Dynamics, Challenges and Priorities Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
ANUPAMA GV, Anand Babu, PADMAJA R and BANTILAN MCS. 2006. ICRISAT research impact and the challenges ahead. Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
ANUPAMA GV, DEEPTHI H and BANTILAN MCS. 2006. Partnerships - strengthening synergies @ GT-IMPI. Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
ARUNA R, Nigam SN, Waliyar F, Upadhyaya HD, Reddy SV, Kanaka Reddy and Reddy AGS. 2006. Aflatoxin resistance breeding at ICRISAT Center. [Abstract] Page 39 *in* International Groundnut Conference on Groundnut Aflatoxin and Genomics, 5-9 November 2006, Guangzhou, Guangdong, China.
Ashok Kumar A, JANILA P, **Sudhakar R** and HEMALATHA V. 2006. Haritha – Fusarium wilt resistant castor variety suitable to rainfed areas. **In**: Indian Science Congress, January 3 – 7, 2006. ANGRAU, Hyderabad.
Aswani K, Basandrai A, BASABDRAI D, Pande S, **Sanjay K** and **Thakur HL**. 2006. Effect of plant age on ascochyta blight (*A. rabiei*) in chickpea. [Abstract] C-5, Page 39 *in* 1st International Ascochyta workshop on grain Legumes, (Ascochyta 2006) 2-6 July 2006, Le Tronchet, France.
BANTILAN MCS and PADMAJA R. 2006. Social networks in Rural SAT Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
BANTILAN MCS, **Parthasarathy D**, PADMAJA R and Chopde VK. 2006. Building social capital: Collective action, adoption of agricultural innovations, and poverty reduction in the Indian semi-arid tropics. Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
BANTILAN MCS, Rao KPC, **Mruthyunjaya, Acharya SS** and PADMAJA R. 2006. Vision for rainfed agriculture, Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru. Poster presented at Partnerships day on November 14, 2006 at ICRISAT, Patancheru.
BANTILAN MCS, Shiferaw B and PADMAJA R. 2006. Social Science Framework for ICRISAT Research on Natural Resource Management. Poster presented at Meeting on "Partnerships - strengthening synergies" November 14, 2006. ICRISAT, Patancheru.
BHATNAGAR-MATHUR P, **JYOSTNA DEVI M,** VANI G, Vadez V, Verma DPS and Sharma KK. 2006. Physiological responses of chickpea expressing the P5CSF129A gene under water stress conditions. In: Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, ICRISAT, Feb. 2-4, 2006
BHATNAGAR-MATHUR P, **JYOTSANA DEVI M**, **Srinivas Reddy D**, Vadez V, YAMAGUCHI-SHINOZAKI K and Sharma KK. 2006. Stress-inducible expression of *At* DREB1A in transgenic peanut (*Arachis hypogaea* L.) improves transpiration efficiency under water limiting conditions *in* Sixth Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, University of Delhi, Delhi, Dec. 2-4, 2006.

Poster Papers:

BHATNAGAR-MATHUR P, **JYOTSANA DEVI M, Srinivas Reddy D,** Vadez V, YAMAGUCHI-SHINOZAKI K and Sharma KK. 2006. Expression of *Arabidopsis thaliana* DREB1A in transgenic peanut (*Arachis hypogaea* L.) for improving tolerance to drought stress *in* Arthur M. Sackler Colloquia, National Academy of Science, USA. April 3-5, 2006. BILLOT C, Deu M, Rami J-F, Rivallan, Hash CT, Ramu P, *Folkertsma RT,* BANTTE K, Upadhyaya HD, **Li Y** and **Fonceka D**. 2006. Insight into genetic diversity analysis of sorghum biocolor- use of SSR markers. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Chander Rao S, Kumar PL, Reddy AS, Swamy Krishna T, Waliyar F, Nigam SN, **LAXMINARASU M** and Sharma KK. 2006. Evaluation of transgenic peanut plants against peanut bud necrosis disease (PBND) under greenhouse and field conditions. [Winner of the Best Poster Award]. Indian Journal of Virology 17(2):135.
Chander Rao S, Lava Kumar P, Reddy AS, Swamy Krishna T, Waliyar F, Nigam SN, **LAXMINARASU M** and Sharma KK. 2006. Development and evaluation of transgenic peanut plants against peanut bud necrosis disease (PBND) under greenhouse and field conditions. Pages 101-102 *in* Proceedings of XVI Annual Convention and International Symposium on Management of Vector-Borne Viruses, 7-10 Feb 2006, ICRISAT Center, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
Chandra S, RUPA SRIDEVI K, Hussain SA, Rami Reddy B, JAYASHREE B, Hoisington DA, *Davenport G*, *Crossa J*, and *McLaren GC*.. 2006. iMAS: an integrated decision support system for marker-aided breeding. Presented at GCP ARM in Brazil, 12-17th September 2006.
Clement SL, Sharma HC, Elberson LR and Muehlbauer FJ. 2006. Lepidoptera pest resistance in wild Cicer germplasm and interspecific progeny. Poster Presented at the Annual Meeting of Entomological Society of America, 10 -13 Dec 2006, Indianapolis, Indiana, USA.
Collins A, Simon R, Davenport G, Chandra S, JAYASHREE B, *de Villiers E* and *Bruskiewitz R*. 2006. HPC: High performance computing – Reaching out for bioinformatics research. Presented at GCP ARM in Brazil.
Collins A, *Simon R*, *Davenport G*, JAYASHREE B, Chandra S, *Etienne de Villiers* and *Bruskiewich R*. 2006. HPC: High Performance computing reaching out for Bioinformatics Research. Poster presented at the GCP ARM at Sao Paolo, Brazil, 12-17th September 2006.
Deshpande SP, Folkertsma RT, Mehtre SP, Sharma HC, Hash CT, Reddy BVS and Borikar ST. 2006. Genetic studies and QTL mapping for shoot fly resistance and its components traits in Sorghum bicolor (L.) Moench. Paper Presented in XIV International Conference on "Plant and Animal Genome, 10 – 14 January, San-Diego, California, USA.
Deshpande SP, Folkertsma RT, S P Mehtre, Sharma HC, Hash CT, Reddy BVS and Borikar ST**.** 2006. Genetic studies and QTL mapping for shoot fly resistance and its component traits in *Sorghum bicolor* (L.) Moench. Poster presented at Plant and Animal Genome XIV held at San Diego, California, USA from January 14 to 18, 2006. http://www.intl-pag.org/14/abstracts/PAG14_P377.html
Dhillon MK, Sharma HC and **Romeis J**. 2006. Influence of *Bacillus thuringiensis* δ-endotoxins and *Helicoverpa*–resistant chickpea genotypes on development and survival of the parasitoid, *Campoletis chlorideae*. In: Annual Pulse Network Meeting 5-7 December 2006, Indo-Swiss Collaboration in Biotechnology, Department of Environmental Biology, University of Delhi, India.
Dhliwayo C, Makurira H, *Mupangwa W*, Love D and Twomlow S. 2006. An on farm comparison of conservation agriculture practices and conventional farm practices on soil hydrology and maize yield. [Volume of Abstracts] *in* 7th Waternet/WARFSA/GWP-SA Symposium ' Mainstreaming Integrated Water Resources Management in the Development Process. Lilongwe, Malawi, 1-3 November 2006.
Gwata ET and Silim SN. 2006. Exploiting pigeonpea [*Cajanus cajan* (L.) Millsp.] landraces cultivar development in eastern and southern Africa. First International Conference on Indigenous Vegetables and Legumes, 12 – 15 December 2006, Patancheru, India.
HAMEEDA B, HARINI G, Rupela OP, Wani SP and **Gopal Reddy**. 2006. Rock phosphate solubilization and rhizosphere colonization by bacteria isolated from composts and macrofauna for increasing yield of maize. Agribiotech: International Conference on Biotechnology for Sustainable Agriculture and Agro-Industry, Hyderabad, Andhra Pradesh, India.
Hash CT, Punna Ramu, Kassahun B, Folkertsma RT, JAYASHREE B, Prasad PVNS, Chandra S, Ashok Kumar Ch, Senthilvel S, HAUSSMANN BIG, Kiambi D and Hoisington DA. 2006. Exploiting rice-sorghum synteny to map additional SSR markers in genomic regions associated with sorghum QTLs for *Striga* resistance and stay-green. International Symposium on Integrating New Technologies

Poster Papers:

for Striga Control: Towards Ending the Witch-hunt, 5-11 Nov 2006, Addis Ababa, Ethiopia.
Hash CT, Rizvi SMH, Vadez V, JAYASHREE B, Senthilvel S, Reddy AR, Chandra Sekhar A, Reddy LVB, Reddy MK and Sudhakar Reddy P. 2006. Generating stress response enriched ESTs targeting a major drought tolerance QTL in pearl millet. Generation Challenge Programme Annual Research Meeting, 12-16 Sep 2006, Sao Paulo, Brazil.
Hash CT, Sharma A, Nepolean T and Senthilvel S. 2006. Development and application of tools for marker-assisted breeding in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Page 22 *in* Invited paper (W66) presented in Sorghum and Millets Workshop at Plant & Animal Genomes Conference- XIV, January 14-18, 2006, Town & Country Convention Center, San Diego, USA. http://www.intl-pag.org/14/abstracts/PAG14_W66.html
HAUSSMANN BIG, **Boubacar A, Boureima SS** and Dodo H. 2006. Towards a striga-resistant genepool in pearl millet. Poster presented at at the International Symposium on Integrating New Technologies for Striga Control, November 5-11, 2006 in Addis Ababa, Ethiopia.
HAUSSMANN1 BIG, Boureima SS, **Boubacar A** and Vigouroux Y. 2006. Multiplication and Preliminary Characterization of West and Central African Pearl Millet Landraces.
Hazelkamp T, Bink M, Chandra S, *Davenport G, Endresen D, Gaiji S, Simon R, Sood R* and *Skofic M*. 2006. Management of the GCP Central Registry. Presented at GCP ARM in Brazil.
Hoisington D, Upadhyaya HD, Dwivedi SL, Baum M, Udupa SM, Furman BJ, Chandra S, Eshwar K, Gowda CLL and **Singh S**. 2006. Genotypic and phenotypic variation in the global collection of chickpea (*Cicer arietinum* L.). Presented at the Third International Conference on Legume Genomics and Genetics, 9-13 April 2006, Brisbane, Queensland, Australia.
Hoisington DA, JAYASHREE B, SANTIE DE VILLEIRS, Kiambi Dan, *FERGUSON M, HEARNE SARAH,* and *Etienne de Villiers*. 2006. Installation and implementation of ICRISAT-LIMS at BeCA facility and IITA-Ibadan. Poster presented at the GCP ARM at Sao Paolo, Brazil, 12-17th September 2006
Hoisington DA, MALLIKARJUNA N, Upadhyaya HD, Gaur PM, Nigam S, Saxena KB, Hash CT, Waliyar F, Kumar PL, Vadez V and Varshney R. 2006. Tapping crop diversity and genomics to tackle problems faced by farmers in the semi-arid tropics *in* ASA - CSSA – SSSA International Annual Meetings, Nov 12-16, Indianapolis, USA.
Hoisington DA, Senthilvel S, Rizvi M and Hash CT. 2006. Predicting Phenotypes from Genotypes - The Application of Comparative Genomics. Page 69 *in* Invited paper (W278) presented in Genomics-Assisted Breeding workshop at Plant & Animal Genomes Conference- XIV, January 14-18, 2006, Town & Country Convention Center, San Diego, USA. **http://www.intl-pag.org/14/abstracts/ PAG14_W278.html**
HOMANN S, VanRooyen A, MOYO T and **NENGOMASHA Z**. 2006. Strengthening livestock market flows and feeding practices for improved livelihoods in southern Zimbabwe. Poster presented at Deutscher Tropentag 2006 Bonn, October 11-13, 2006, Conference on International Agricultural Research for Development. Poster available at http://www.tropentag.de/2006/abstracts/posters/408.pdf
HOMANN S. VanRooyen A, MOYO T and **NENGOMASHA Z**. 2006. Strengthening livestock market flows and feeding practices for improved livelihoods in southern Zimbabwe. Poster presented at Deutscher Tropentag 2006 Bonn, October 11-13, 2006, Conference on International Agricultural Research for Development. Poster available at http://www.tropentag.de/2006/abstracts/posters/408.pdf.
Isaac Minde and **Michael Waithaka**. 2006. Rationalization and Harmonization of Seed Policies and Regulations in Eastern and Central Africa: Effecting Policy Change through Private-Public Partnerships. Paper presented at the 26th International Agricultural Economics Conference, Gold Coast, Australia, 17 August 2006.
Jagadeesh VT*, JAYASHREE B*, Senthilvel S, Hash CT, Hoisington DA and Chandra S. 2006. Comparative genomics approach for the design of primers to conserved intron scanning regions in pennisetum glaucum. (* joint first authors).
JANILA P and Ashok Kumar A. 2006. Isolation of induced lethal mutants in castor (*Ricinus communis* L.) *in* Indian Science Congress, January 3 – 7, 2006. ANGRAU, Hyderabad.
JAYASHREE B, Subhash Chandra, Hoisington DA and Rajeev K Varshney. 2006. Integration of HPC facilities in the GCP toolbox : 2005-27 ICRISAT activities. Poster presented at the GCP ARM at Sao Paolo, Brazil, 12-17th September 2006
JAYASHREE B, Subramanyam G, Hoisington DA and Chandra S. Information Management Systems for High Throughput Crop Genotyping. Poster presented at the International conference on Bioinformatics INCOB ’06 held in Delhi, 18-20th December 2006.

Poster Papers:

Johansen C, Musa AM, Kumar Rao JVDK, Harris D, **Shahidullah AKM** and LAUREN JG. 2006. Seed priming with molybdenum alleviates molybdenum deficiency and poor nitrogen fixation of chickpea in acid soils of Bangladesh and India. Poster presented at the 18th World Congress of Soil Science. July 9-15, 2006 - Philadelphia, Pennsylvania, U.S.A.
JYOSTNA DEVI M, BHATNAGAR-MATHUR P, VANI G, Vadez V, Verma DPS and Sharma KK. 2006. Over expression of *Vigna P5CSF129A* gene in chickpea for enhancing drought tolerance *in* Sixth Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, University of Delhi, Delhi, Dec. 2-4, 2006.
JYOTHI T, Hash CT and Anwar SY. 2006. SSR marker assisted backcross introgression of QTL for host plant resistant to (*Atherigona soccata* Rond.) in sorghum (*Sorghum bicolor* Moench). [Abstracts. P-III-20] Page 95 *in* International Symposium on Frontiers in Genetics in Biotechnology - Retrospect and Prospect, 8th to 10th January, 2006. Department of Genetics & Biotechnology, Osmania University, Hyderabad.
Kesava Rao AVR, Piara Singh and Wani SP. 2006. Agroclimatic Characterization of Benchmark Watersheds: TATA-ICRISAT-ICAR Project. Poster presented during the Review and Planning Meeting for the TATA-ICRISAT-ICAR Project on “Combating Land Degradation and Increasing Productivity in Madhya Pradesh and eastern Rajasthan” held during 19-20 July 2006 at ICRISAT, Patancheru.
Kesava Rao AVR, Wani SP and Balaji V. 2006. NOAA Satellite Imagery Receiving System at ICRISAT, Patancheru. Poster presented during the Review and Planning Meeting for the TATA-ICRISAT-ICAR Project on “Combating Land Degradation and Increasing Productivity in Madhya Pradesh and eastern Rajasthan” held during 19-20 July 2006 at ICRISAT, Patancheru.
Ki, **KS**, Alexander G, Saxena KB, Vellaikumar S, Prasad KVSV and Blümmel M. 2006. Relations between laboratory traits in 10 pigeonpea forages and their intake, digestibility and nitrogen retention in sheep. Page 11 *in* Technological Interventions in Animal Nutrition for Rural Prosperity: Volume I Abstracts (Bakshi MPS and Wadhwa M, eds.). Proceedings of XIIth Animal Nutrition Conference, January 7-9, 2006, College of Veterinary Science and Animal Husbandry, Anand Agricultural University, Anand, India
Kiambi D, Hoisington D, Folkertsma R, Hash T, HAUSSMAN B, DE VILLIERS S, Parzies H, Geiger H, Rabbi I and Bhandari N. 2006. Introgression of *Striga* resistance QTL in Sorghum through marker assisted backcrossing and farmer-participatory selection. Poster presented at the International *Striga* Symposium held in Addis Ababa, Ethiopia from 5-11 November 2006.
Kileshye Onema J-M, Mazvimavi D, Love D and MUL M. 2006. Effects of dams on river flows of Insiza River, Limpopo Basin, Zimbabwe. World Water Week, Stokholm, Sweden, 20-26 August, 2006.
LATHA TKS, APARNA V, Siva Prasad R, Kumar PL, **Chauhan VB** and Waliyar F. 2006. Recent advances in the detection of Pigeonpea sterility mosaic virus. [Abstracts] Pages 119-120 *in* International Symposium on Management of Vector-Borne Viruses, 7 – 10 ICRISAT, Patancheru 502 324, AP, India.
LI Y, Folkertsma R, Hash CT and Li G. 2006. Construction SSR markers linked to resistance in sorghum against the spotted stem borer. [Final Abstracts Guide] Page 363 *in* Plant & Animal Genome XIV, Jan 14–18 2006, Town & Country Hotel, San Diego, CA, USA. http://www.intl-pag.org/14 /abstracts/.
Love D, **Moyce W** and **Ravengai S**. 2006. Livelihood challenges posed by water quality in the Mzingwane and Thuli river catchments, Zimbabwe. 7th WaterNet/WARFSA Symposium, Lilongwe, Malawi, November 2006.
Maheswaran M, GEETHANJALI S, Vinod KK, Meenakshisundaram P, Elaiyabharathi T, Kadirvel P, Senthilvel S, **Govindaraj P, Arumugachamy A, Shanmugasundaram P, MALARVIZHI P** and **Gunathilagaraj K**. 2006. Tracing quantitative trait loci – the best and rest with reference to brown plant hopper resistance and nitrogen uptake in rice. Second National Plant Breeding Congress, 1-3 March, 2006, Tamil Nadu Agricultural University, Coimbatore, India. Pp256-257.
Manindra S Hanspal*, JAYASHREE B*, Ramesh N, Hoisington DA and Chandra S. 2006. In silico identification of SNPs from sorghum candidate sequence data and their distribution on the rice chromosome. Poster presented at the Bioinformatics session of the 2nd IRCC 2006, held in Delhi, India between Oct 9-13th 2006. (* joint first authors).
Mati BM. 2006. IMAWESA project Poster
Mati BM. 2006. Poster of the Resolution of the 2nd workshop on agricultural water management in Eastern & Southern Africa.

Poster Papers:

MUKHOPADHYAY R, Rajaram V, Ramu P, Ashokkumar C, **Kavi Kishor PB, Sivaramakrishnan S**, Senthilvel S, JAYASHREE B and Hash CT. 2006. Development Of TRAP Markers In Pearl Millet For Genes Related To Nutritional Quality Of Straw, Terminal Drought Tolerance, and Salinity Stress Tolerance. Poster 204, Plant & Animal Genomes Conference- XIV, January 14-18, 2006, Town & Country Convention Center, San Diego, USA. p152. http://www.intl-pag.org/14/abstracts/PAG14_P204.html.
MUKHOPADHYAY R, Rajaram V, Ramu P, **Kavi Kishor PB**, Senthilvel S, JAYASHREE B and Hash CT. 2006. Target Region Amplification Polymorphism (TRAP): A novel approach for development of trait-specific markers in pearl millet for genes related to salinity stress tolerance. *In* Abstract, International Symposium on 'Frontiers in Genetics and Biotechnology – Retrospect and Prospect', 8-10 January, 2006, Osmania University, Hyderabad, India, p100.
MUKHOPADHYAY R, **SUNITHA MSL**, Deshpande SP, **Kavi Kishor PB**, Bhaskar Raj AG, Senthilvel S and Hash CT. 2006. Target Region Amplification Polymorphism (TRAP): A new tool for mapping quantitative traits in pearl millet. *In* Abstract, International Symposium on 'Frontiers in Genetics and Biotechnology – Retrospect and Prospect', 8-10 January, 2006, Osmania University, Hyderabad, India, p100.
MUKHOPADHYAY R, SUNITHA MSL, Deshpande SP, Kavi Kishore PB, Bhasker Raj AG, Senthilvel S and Hash CT. 2006. Page 100 *in* Target Region Amplification Polymorphism (TRAP): A new tool for mapping quantitative traits in pearl millet. Poster presented in "International Symposium on Frontiers in Genetics and Biotechnology – Retrospect and Prospect" held at Osmania University, Hyderabad from 8 to 10 January 2006.
Mupangwa W, Twomlow S, Hove L and **WALKER S**. 2006. Effect of mulching and minimum tillage on Maize (*Zea may L.)* yield and water content of clayey and sandy soils. [Volume of Abstracts] Page 62 *in* Poster Presentation 7th Waternet/WARFSA/GWP-SA Symposium 'Mainstreaming Integrated Water Resources Management in the Development Process, Lilongwe, Malawi, 1-3 Septmber 2006.
NCUBE N, Giller K, van Wijk M, Dimes JP and Twomlow S. 2006. Productivity and residual benefits of grain legumes to sorghum under semi arid conditions in south-western Zimbabwe. Tropentag 2006: International Research on Food Security, Natural Resource Management and Rural Development , Institute of Crop Science and Resource Conservation – University of Bonn, Germany, October 11 - 13, 2006.
NCUBE N, Giller K, van Wijk M, Dimes JP and Twomlow S. 2006**.** Productivity and residual benefits of grain legumes to sorghum under semi arid conditions in south-western Zimbabwe. Tropentag 2006: International Research on Food Security, Natural Resource Management and Rural Development , Institute of Crop Science and Resource Conservation – University of Bonn, Germany, October 11 - 13, 2006
Ngaboyisonga C, Njoroge K, *Kirubi D* and Githiri SM. 2006. Effects of low nitrogen and drought on grain yield and endosperm hardness of quality protein maize single cross hybrids. International Plant Breeding Symposium, Mexico City, 20-25 August 2006. CIMMYT.
Ntare B, Waliyar F and DIALLO AT. 2006. Amélioration de l'arachide en Afrique de L'ouest: les variétés restantes aux maladie foliaires, a la sécheresse et a l'aflatoxine. Presented at the Agricultural Research Week in Mali, 5-9 June 2006, Bamako, Mali.
Ntare B, Waliyar F and DIALLO AT. 2006. Amélioration de l'arachide en Afrique de L'ouest: Nouvelles variétés d'arachide de bouche (ARB). Presented at the Agricultural Research Week in Mali, 5-9 June 2006, Bamako, Mali
Okello JJ and Narrod CM. 2006. "Seizing the opportunity: Kenya's green bean family farmers achieve traceability and expand production via collective action and public-private partnerships" Selected poster, American Agricultural Economics Association meeting, Long Beach, July 22-27, 2006. Publisher: American Association of Agricultural Economics.
Pande S, Gaur PM, **Basandrai AK**, MALLIKARJUNA N, Knight EJ and SHARMA M. 2006. Advances in host plant resistance in aschochyta blight of chickpea. [Abstract] B-9, Page 17 *in* 1st International Ascochyta workshop on grain Legumes, (Ascochyta 2006) 2-6 July 2006, Le Tronchet, France.
Parthasarathy Rao P and **Birthal PS**. 2006. Livestock sector in the Semi-Arid Tropics: Implications for research. Prepared for the Partnership Day 15 November 2006, Patancheru, ICRISAT.
Parthasarathy Rao P and **Birthal PS**. 2006. Typology of crop livestock systems in India. Prepared for the Partnership Day 15 November 2006, Patancheru, ICRISAT.

Poster Papers:

Parthasarathy Rao P, Gurava Reddy K, Reddy BVS, Ravinder Reddy Ch, Gowda CLL, and Alur A. 2006. Enhancing livelihoods of small-scale sorghum producers in Asia: Innovation through Coalition Approach. Presented at the GFAR Triennial conference Poster Competition on ARD: Evidence of contributing to achieving the MDGS,, 8-10 November 2006 New Delhi, India.
Pathak M, SHARMA M, Narayana Rao J and Pande S. 2006. Phytophthora Blight of Pigeonpea in the Deccan Plateau of India. [Abstract] Page 32 *in* National Symposium on Emerging Plant Diseases their Diagnosis and Management, 31Jan - 2Feb 2006, Department of Botany, University of West Bengal, Siliguri, West Bengal, India.
Prasad KVSV, Ravi D, Bidinger F, Hash CT and *Blümmel M*. 2006. Relations between laboratory traits of 14 pearl millet stover and their digestibility, intake and nitrogen balance in sheep. Proceedings XIIth Animal Nutrition Conference in Technological Interventions in Animal Nutrition for Rural Prosperity, 7th-9th Jan. 2006, College of Veterinary Science and Animal Husbandry, Anand Agricultural University, Anand-388 110, Gujarat, India. FFR 25.
Prasanth VP, Chandra S, David Hoisington and JAYASHREE B. 2006. Allelobin: a program for allele binning of microsatellite markers. Poster presented at the International conference on Bioinformatics INCOB '06 held in Delhi, 18-20th December 2006.
Prasanth VP, Chandra S, Hoisington DA and JAYASHREE B. 2006. Allelobin: a program for allele binning of microsatellite markers. Poster presented at the International conference on Bioinformatics INCOB '06 held in Delhi, 18-20th December 2006.
Rajashekar Reddy N, Ashok Kumar A, JANILA P and **Sudhakar R**. 2006. Efficient screening technique for botrytis grey rot disease in castor (*Ricinus communis* L.). **In**. Proceedings of national seminar on "Drought adaptations for sustainable agriculture and livelihood in dry land areas – problems prospects and policies", February 15-16, 2006. RARS, Palem, ANGRAU. It was awarded 2nd in best poster category.
Ramu P, Kassahum B, Ashok Kumar C, JAYASHREE B, Folksterma RT, *MAHALAKSHMI V*, **Ananda L Reddy**, Fakrudin B and Hash CT. 2006. Development and mapping of EST-SSR markers in sorghum for comparative mapping with rice. PAG-XIV, San Diego, CA, 14-18 January 2006.
Rao KPC, BANTILAN MCS, **Katar Singh**, **Subrahmanyam S,** PRIYA DESHINGKAR, Parthasarathy Rao P and Bekele Shiferaw. 2006 Overcoming Poverty in Rural India: Focus on Rainfed Semi-arid Tropics, Presented at Partnerships day on November 14, 2006 at ICRISAT.
Rao KPC, **Kinuthia R** and **Ndegwa WG**. 2006. Making the Best of Climate – adapting agriculture to climate variability. Presented at: Inception workshop of project Making the Best of Climate, February 6-10, 2006 Nairobi, Kenya. (Poster published in both English and French).
Rao KPC, Mohan Rao Y, Chopde VK and Kumara Charyulu D. 2006 Searching for alternate pathways to escape from Poverty 2006, Presented at Partnerships day on November 14, 2006 at ICRISAT.
Reddy AS, Kumar PL, Nigam SN and Waliyar F. 2006. Effect of virus titer and date of inoculation on infectivity of *Peanut bud necrosis virus* (PBNV), *Tobacco streak virus* (TSV), and *Indian Peanut clump virus* (IPCV) to groundnut. Indian Journal of Virology 17(2):146.
Reddy BVS, **Ramesh S, Longvah T**, Upadhyaya HD and SANJANA REDDY P. 2006. Prospects of Breeding for Micronutrient-Dense Sorghums. Poster presented at the International Plant Breeding Symposium, 20-25 August 2006, Mexico City, Mexico.
Ridsdill-Smith JT, Sharma HC, Gaur PM, Evers M, Kilian A and Edwards O. 2006. Segregation of resistance to *Helicoverpa* spp. from *Cicer reticulatum* in crosses with cultivated chickpea, *C. arietinum in* International Conference for Legume Genetics and Genomics, 9 – 13 April 2006. ARC Centre of Excellence for Integrative Legume Research, Brisbane, Queensland, Australia
RUPA KANCHI, Chandra S, Syed Asif Hussain, Rami Reddy B, JAYASHREE B, Hoisington D, Guy Davenport, Jose Crossa and Graham McLaren. 2006. IMAS: an integrated decision support system for marker aided breeding. Poster presented at the International conference on Bioinformatics INCOB '06 held in Delhi, 18-20th December 2006.
RUPA KANCHI, Chandra S, Syed Asif Hussain, Rami Reddy *B*, JAYASHREE B, Hoisington DA, Guy Davenport, Jose Crossa and Graham McLaren. 2006. IMAS: an integrated decision support system for marker aided breeding. Poster presented at the International conference on Bioinformatics INCOB '06 held in Delhi, 18-20th December 2006.
Rupela OP, **Rahman SJ**, Ranga Rao GV, **RAMA J**, **JYOTHSNA JSS** and Humayun P. 2006. Protecting vegetables from insect-pests using low-cost and biological options – a two-year on-farm experience.

Poster Papers:

Saqalli M. 2006. IYDD 22 September 2006 – Brussels, Belgium. *International Year of Deserts and Desertification* Conference "Desertification: Migration, Health, Remediation and Local Governance". Title: Understanding social constraints in sahelian Niger communities as a decision-support tool for development operators.
Sastry DVSSR, Upadhyaya HD and Gowda CLL. 2006. Seed quality of genetic resources at ICRISAT. Poster presented at XII National Seed Seminar on Prosperity Through Quality Seed 24-26 February 2006, Hyderabad, Andhra Pradesh, India by Indian Society of Seed Technology, New Delhi and Acharya NG Ranga Agricultural University, Hyderabad.
Sharma HC and Dhillon MK. 2006. Effect of *Bacillus thuringiensis* toxins and transgenic plants on survival and development of the parasitoid, *Campoletis chlorideae*, and the coccinellid predator, *Cheilomenes sexmaculatus*. Page 17 *in* Annual Pulse Network Meeting 2-4 February 2006, Indo-Swiss Collaboration in Biotechnology, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., India.
Sharma HC and Dhillon MK. 2006. Effect of *Bacillus thuringiensis* δ-endotoxins on the *Helicoverpa* parasitoid, *Campoletis chlorideae* and the coccinellid predator, *Cheilomenes sexmaculatus*. Page 14 *in* Annual Pulse Network Meeting 5-7 December 2006, Indo-Swiss Collaboration in Biotechnology, Department of Environmental Biology, University of Delhi, India.
Sharma HC, Dhillon MK and **Romies J**. 2006. Influence of Cry1Ab and Cry1Ac intoxicated *Helicoverpa armigera* larvae on the survival and development of the parasitoid, *Campoletis chlorideae* In: Annual Pulse Network Meeting 2-4 February 2006, Indo-Swiss Collaboration in Biotechnology, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., India.
Sharma KK, Lava KumarP, Waliyar F, Nigam SN, LAVANYA M, Reddy AS and Swamy Krishna T. 2006. Development and evaluation of transgenic peanuts for induced resistance to the Indian peanut clump virus. Page 37 *in* Proceedings of XVI Annual Convention and International Symposium on Management of Vector-Borne Viruses, 7-10 Feb 2006, ICRISAT Center, Patancheru 502 324, Andhra Pradesh, India. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.
Sharma KK, Waliyar F, Lava Kumar P, Reddy SV, Reddy RK, Muthukrishnan S, LAVANYA M, Nigam SN, ARUNA R and Hoisington DH. 2006. Development and Evaluation of Transgenic Groundnut Expressing the Rice *Chitinase* Gene for Resistance to *Aspergillus flavus in* International Conference on Groundnut Aflatoxin Management & Genomics, 5-9 Nov 2006, Guangdong Hotel, Guangzhou, Guangdong, China.
Sharma KL, PADMAJA KV, **Suryanarayan Reddy M, Chandrasekhar Rao P, Grace JK, Srinivas K** and **Ramesh V**. 2006. Direct and residual effects of phosphorus fertilization of rainfed sorghum (*Sorghum vulgare* L.) and its effect on P adsorption and availability in semi-arid tropical Alfisols *at* the 18th World Congress of Soil Science- Frontiers of Soil Science, Technology and Information Age. July 9-15, 2006 - Philadelphia, Pennsylvania, USA.
SHARMA M, Pathak M, Narayana Rao J and Pande S. 2006. Comparison of resistance screening techniques for Ascochyta blight and Botrytis grey mould in chickpea. [Abstract] Page 33 *in* National Symposium on Emerging Plant Diseases their Diagnosis and Management, 31Jan - 2Feb 2006, Department of Botany, University of West Bengal, Siliguri, West Bengal, India.
Shiferaw B and Silim S. 2006. The Adoption and Impact of Improved Pigeonpea Varieties in Tanzania.
SIART S, WELTZIEN E, *Kanoute M* and Hoffmann V. 2006. Farmers'sorghum seed sources after a drought year in Southern Mali. Poster presented at Deutscher Tropentag, 5-7 October 2006, Bonn, Germany.
SIREESHA K, Ranga Rao GV and Lava Kumar P. 2006. Biological and molecular characterization of six isolates of *Helicoverpa armigera* Nucleopolyhedrovirus (HaNPV) from different geographic locations, India 2006. Indian Journal of Virology, Official Publication of Indian Virological Society 17(2):156-157.
Subba Reddy Ch V, Sreenivasulu P and Kumar PL. 2006. Detection of *Sugarcane streak mosaic virus* (SCSMV) in sugarcane explants meant to generate virus-free sugarcane by tissue culture technology. Indian Journal of Virology 17(2):130.
Upadhyaya HD, BHATTACHARJEE R, Hoisington DA, Chandra S, Varshney RK, Reddy KN and Saxena KB. 2006. Molecular characterization of pigeonpea [*Cajanus cajan* (L.) Millspaugh] composite collection. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.

Poster Papers:

Upadhyaya HD, BHATTACHARJEE R, Hoisington DA, Chandra S, Varshney RK, Singh S, **Valls JFS**, **Moretzsohn MC**, **LEAL-BERTIOLI S**, **PATRICIA GUIMARÃES** and **David Bertioli**. 2006. Molecular characterization of groundnut (*Arachis hypogaea* L.) composite collection. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Hash CT, Senthilvel S, Varshney RK, Hoisington DA, Rai KN, Reddy KN, Thakur RP and Chandra S. 2006. Development of composite collection and genotyping of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Hoisington DA, Dwivedi SL, *Baum M, Udupa SM, FURMAN BJ*, Chandra S, Eshwar K, Gowda CLL, Singh S and Prasanth VP. 2006. Genotypic and Phenotypic Variation in the Global Collection of Chickpea (*Cicer arietinum* L.). Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Varshney RK, Hash CT, Hoisington DA, Gowda CLL, Gopal Reddy V, Chandra S, BHARTHI A, LALITHA N and DEVOS KM. 2006. Development of composite collection and genotyping of foxtail millet [*Setaria italica* (L.) Beauv.] composite collection. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Upadhyaya HD, Varshney RK, Hoisington DA, Gowda CLL, Hash CT, Gopal Reddy V, Chandra S, BHARTHI A and LALITHA N. 2006. Genotyping composite collection of finger millet [*Eleusine coracana* (L.) Gaertn]. Poster presented in the Generation Challenge Program Annual Research Meeting, 12-16 September 2006, Sao Paulo, Brazil.
Vadez V, DEVI MJ, BHATNAGAR-MATHUR P, *Serraj* R, Sharma KK. 2006. Evaluation and Deployment of Transgenic Drought-Tolerant Groundnut at ICRISAT. Poster presented at the Annual Review Meeting of the Generation CP, Sao Paulo, Brasil, 12-16 Sept 2006.
Vadez V, Jyotsna Devi M, Bhatnagar-Mathur P, Serraj R and Sharma KK. 2006. Evaluation and Deployment of Transgenic Drought-Tolerant Groundnut at ICRISAT. Poster presented at the Annual Review Metting of the Generation CP, Sao Paulo, Brasil, 12-16 Sept 2006.
Vadez V, Krishnamurthy L, Gaur PM, Upadhyaya HD, Hoisington D and Varshney RK. 2006. Genetic variability for salinity tolerance in chickpea. 3rd International Conference on Legume Genomics and Genetics, Brisbane, Australia 9-13 April, 2006.
Vadez V, Krishnamurthy L, Gaur PM, Upadhyaya HD, Hoisington DA, Varshney RK, Turner NC and Siddique KMH. 2006. Tapping the large genetic variability for salinity tolerance in chickpea. Proceeding of the Australian Society of Agronomy meeting (10-14 Sept 2006). http://www.regional.org.au/au/asa/2006/concurrent/environment/4561_vadez.htm
Vadez V, Krishnamurthy L, Varshney RK, *Serraj* R, DEVI MJ, Nigam SN, ARUNA R, Moss B, SEETHA KANNAN, Hoisington D, RUPA K and Chandra S. 2006. Variation in transpiration efficiency in a groundnut (*Arachis hypogaea* L.) mapping population Poster presented at the Annual Review Meeting of the Generation CP, Sao Paulo, Brasil, 12-16 Sept 2006.
Valluru R, RIZVI R, Hash CT and Vadez V. 2006. Microdosing, an efficient phosphorus application strategy to improve seedling establishment IN pearl millet HYBRIDS (*Pennisetum americanum* L.) under nutrient stressed environments. Conference **"**Plant Nutrition meets Plant Breeding"**.** Universität Hohenheim, Stuttgart 26 – 28 September 2006.
Van Mourik T, WELTZIEN E, HAUSSMANN BIG. 2006. Integrated Striga managment (ISM), at ICRISAT in West Africa. Poster Presented at Internatioanl Striga Symposium, held at Addis Abeba, Ethiopia, 2-6 November 2006.
VANI G, BHATNAGAR-MATHUR P, **JYOSTNA DEVI M**, Vadez V, YAMAGUCHI-SHINOZAKI K and Sharma KK. 2006. Development and evaluation of transgenic chickpea for tolerance to drought stress by using *DREB1A* gene from *Arabidopsis thaliana in* Sixth Annual workshop of Indo-Swiss collaboration in Biotechnology & Pulse Network, University of Delhi, Delhi, Dec. 2-4, 2006.
Vellaikumar S, Khan A, Bidinger F, Hash CT and *Blümmel M*. 2006. Variations in fodder value of pearl millet stover when fed to sheep. Proceedings XIIth Animal Nutrition Conference in Technological Interventions in Animal Nutrition for Rural Prosperity, 7th-9th Jan. 2006, College of Veterinary Science and Animal Husbandry, Anand Agricultural University, Anand-388 110, Gujarat, India. FFR 27.

Poster Papers:

Velu G, Rai KN, **Muralidharan V**, Kulkarni VN, Longvah T and **Raveendran TS**. 2006. Grain iron and zinc contents in pearl millet: genetic variability and breeding implications. Poster presented at the International Plant Breeding Symposium, 20-25 August 2006, CIMMYT, Mexico. http://www.cimmyt.org/english/docs/proceedings/IPBS06-Abstracts.pdf
Vincent V, Krishnamurthy L, Gaur PM, Upadhayaya HD, Hoisington D, Varshney RK, Turner NC and Siddique K. 2006. Tapping the large genetic variability for salinity tolerance in chickpea. Presented in the Australian Society of Agronomy meeting, 10-14 September 2006, Perth, Australia.
Waliyar F, Ntare B and DIALLO AT. 2006. Gestion de l'aflatoxine chez l'arachide. Presented at the Agricultural Research Week in Mali, 5-9 June 2006, Bamako, Mali
Waliyar F, Craufurd P, PADMAJA KV, Reddy RK, Reddy SV, Nigam SN and Kumar PL. 2006. Effect of soil application of lime, crop residue and biocontrol agents on pre-harvest Aspergillus flavus infection and aflatoxin contamination in groundnut. In International Conference on Groundnut Aflatoxin Management and Genomics, 5 – 10 November 2006, Gungdong Hotel, Guangzhou, China.
Waliyar F, Lava Kumar P, Sharma KK, Nigam SN and Hoisington D. 2006. Integrated multidisciplinary approach for containing aflatoxin-linked malnutrition in humans and animals. Presented at: International Conference on Biotechnology Approaches for Alleviating Malnutrition and Human Health, 9-11 January 2006, University of Agricultural Sciences, Bangalore, India.
Wani SP, Srinivasarao Ch, Rego TJ, Pardhasaradhi G and **Somnath Roy**. 2006. On-Farm Nutrient Depletion and Buildup in Vertisols Under Soybean (Glycine Max)-Chickpea(Cicer Arietinum) and Soybean-Wheat (Triticum Aestivum) Cropping Systems in Semi Arid Central India. Paper presented at 71 st Annual Convention of Indian Society of Soil Science held at OUAT, Bhubaneswar during 10-13th, Nov, 2006.
Wani SP, Srinivasarao Ch, Rego TJ, Pardhasaradhi G and **Somnath Roy**. 2006. On-Farm Nutrient Depletion and Buildup in Vertisols Under Soybean (Glycine Max)-Chickpea(Cicer Arietinum) and Soybean-Wheat (Triticum Aestivum) Cropping Systems in Semi Arid Central India. Paper presented at 71 st Annual Convention of Indian Society of Soil Science held at OUAT, Bhubaneswar during 10-13th, Nov, 2006.
Wani SP, Srinivasarao Ch, Rego TJ, Pardhasaradhi G, Sahrawat KL, **Rangu Rao**, **Somnath Roy** and **Chourasia AK**. 2006. Benefits of balanced nutrition in participatory watersheds in Madhya Pradesh and Rajasthan. Paper presented at International Symposium on Balanced Fertilization for Sustaining Crop Productivity held at PAU, Ludhiana during 22-25, Nov, 2006.
Wani SP, Srinivasarao Ch, Rego TJ, Pardhasaradhi G, Sahrawat KL, **Rangu Rao, Somnath Roy and Chourasia AK**. 2006. Benefits of balanced nutrition in participatory watersheds in Madhya Pradesh and Rajasthan. Paper presented at International Symposium on Balanced Fertilization for Sustaining Crop Productivity held at PAU, Ludhiana during 22-25, Nov, 2006.
Wani SP. 2006. Available K stock of two major soil regions (alluvial and shrink-swell soils) in India.
Wani SP. 2006. Consortium for Biodiesel Research in Andhra Pradesh.

Software developed in 2006:

JAYASHREE B. 2006. A parallelized version of the popular population genetics software Structure along with user-friendly interfaces and visualization tool called "Webstructure".
JAYASHREE B. 2006. A pipeline of open source tools for sequence analysis (SNP pipeline) adapted to work within a parallel framework. Shared with ILRI-Nairobi.
JAYASHREE B. 2006. Java version of the allele-binning algorithm, "Allelobin", along with the C executable. The software can also be downloaded from the GCP wiki pages.
JAYASHREE B. 2006. Recent releases of the Laboratory Information Management System developed using the Java struts Framework as a platform independent application. Installed at ICRISAT/ILRI-Nairobi and IITA-Ibadan. Recent versions are also available for download through the project page http://www.icrisat.org/gt-bt/lims/lims.asp
Rao KPC. 2006. DSSAT to APSIM Weather translator – software to convert DSSAT weather files into APSIM format
Shiferaw B, Msangi S and Rosegrant MW. 2006. Plausible Futures for Dryland Agriculture in the Semi-Arid Tropics: A Global Analysis with the IMPACT-WATER model. Working Paper. IFPRI, Washington DC, and ICRISAT, Nairobi.

Electronic modules (Websites) developed in 2006:

BANTILAN MCS. 2006. Poverty dynamics and development pathways: VLS generation II. A two and a half hour module. http://www.ctl1.com.
Davison M and Rao KPC. 2006. Weather forecasting more important than ever. In Responding to climate change in Africa – AGFAX radio pack June 2006. http://www.agfax.net/audio/climate/agr06-06-5.mp3.m3u
Diwakar BD and Ranga Rao GV. 2006. E-learning module on groundnut pest management-update. Knowledge Management and Sharing.
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Groundnut Diseases. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Sorghum Production Practices. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Crop-Weather Relationships. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. FAQs on Organic Manures and Fertilizers. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Groundnut Insect Pests. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Groundnut Production Practices. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Micronutrients. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Pearl Millet Diseases. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Pearl Millet Production Practices. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Soil and Soil Health. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Sorghum Diseases. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Sorghum Insect Pests. http://www.vasat.org/learning_resources/learning_resources.htm
Diwakar Boyanapalle and Balaji Venkataraman. 2006. Vermicomposting. http://www.vasat.org/learning_resources/learning_resources.htm
Kesava Rao AVR. 2006. **Agroclimatology of watersheds in relation to crop planning.** Lecture delivered on 23 October 2006, document and PowerPoint presentation distributed to the participants of the training programme on "Water Management for Canadian Baptist Ministries" held at ICRISAT, Patancheru. *(About 30 participants)*
Kesava Rao AVR. 2006. **Contingent plan for coping drought.** Lecture delivered on the afternoon of 11 November 2006, document and PowerPoint presentation (all in Telugu) to the participants of the training programme on "Training of Trainers for Productivity Enhancement In Integrated Watershed Management", held at ICRISAT, Patancheru. *(About 40 participants)*
Kesava Rao AVR. 2006. **Contingent plan for coping drought.** Lecture delivered on the evening of 11 November 2006, document and PowerPoint presentation (all in Telugu) to the participants of the training programme on "Training of Trainers for Productivity Enhancement In Integrated Watershed Management", held at ICRISAT, Patancheru. *(About 35 participants)*
Kesava Rao AVR. 2006. **Contingent planning for weather aberrations**. Lecture delivered on 25 April 2006, document and PowerPoint presentation distributed to the participants of the training program on "Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development" held at ICRISAT, Patancheru. *(About 40 participants)*
Kesava Rao AVR. 2006. **Contingent planning for weather aberrations**. Lecture delivered on 26 April 2006, document and PowerPoint presentation distributed to the participants of the training program on "Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development" held at ICRISAT, Patancheru. *(About 40 participants)*
Marimuthu S. 2006. Agronomic practices for sustaining production, Training Program on Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development, 24 April - 5 May 2006, ICRISAT, Patancheru, Andhra Pradesh.

Electronic modules (Websites) developed in 2006:

Marimuthu S. 2006. Agronomic practices for biofuel plantations, Training Program on Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development, 24 April -5 May 2006, ICRISAT, Patancheru, Andhra Pradesh.
Marimuthu S. 2006. Cropping systems for enhancing land productivity, Training Program on Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development, 24 April -5 May 2006, ICRISAT, Patancheru, Andhra Pradesh.
Marimuthu S. 2006. Medicinal and aromatic plants with supplemental irrigation in rainfed areas, Training Program on Scaling-out the Benefits of Productivity Enhancement Initiatives of Integrated Watershed Development, 24 April -5 May 2006, ICRISAT, Patancheru, Andhra Pradesh.
Nedumaran S and Nageswara Rao V. 2006. Crop and Rainfall insurance: Risk reducing strategy for the farmers, Training of Trainers for Productivity Enhancement in Integrated Watershed Management, 06 −16 November 2006, ICRISAT, Patancheru Andhra Pradesh, India.
Nigam SN and ARUNA R. 2006. A Groundnut Video Compact Disc (VCD) titled 'A Dream Fulfilled" jointly produced by ICRISAT and Aakruthi Agricultural Associates of India (AAI) supported by the IFAD TAG 532-ICRISAT Project.
Piara Singh. 2006. Farmer participatory varietal selection cum yield maximization trials – APRLP training program - April 2006.
Piara Singh. 2006. Water availability, potential yields and yield gaps – APRLP training program – April 2006.
Ranga Rao GV, Balaji V and Suresh Pande. 2006. Utilization of intelligent systems for chickpea plant protection. ICARDA/ICRISAT. ICT-KM collaborative project.
Ravi Chand K, Kumara Charyulu D and Rao KPC. 2006. Developed data entry formats for Rainfall Insurance Main-survey in Cs-pro.
Ravi Chand K, Kumara Charyulu D and Rao KPC. 2006. Developed data entry formats for Migration and Development Programs surveys in Cs-pro.
Ravi Chand K, Kumara Charyulu D and Rao KPC. 2006. Developed data entry formats for Rainfall Insurance Mini-survey in Cs-pro.
Ravi Chand K, Kumara Charyulu D and Rao KPC. 2006. Developed new electronic modules for high frequency round VLS surveys data entry formats in Cs-pro.
ROSANA P MULA and Nedumaran S. 2006. Impact assessment of watershed interventions, Training of Trainers for Productivity Enhancement in Integrated Watershed Management, 06 −16 November 2006, ICRISAT, Patancheru Andhra Pradesh, India
SREEDEVI TK, Shiferaw B and Wani SP. 2006. Adarsha Watershed in Kothapally - Understanding the Drivers of Higher Impact.
Waliyar F. 2006. Video film on Agri-Science Park giving the details of its components, functions, client information, feed back and future strategy
Waliyar F. 2006. Web page on www.agri-sciencepark.icrisat.org containing all details of Agri-Science Park @ ICRISAT.
Waliyar F. 2006. Web page www.aflatoxin.info containing all details of the work related on aflatoxins and its management, conferences and international workshop.

Appendix 2. List of Staff

Internationally Recruited Staff

Name	Title
ICRISAT - Headquarters, Patancheru	
WD Dar	Director General
JDH Keatinge	Deputy Director General-Research
RL Navarro	Director, Communication and Special Assistant to the Director General
Rajesh Agrawal	Director-Finance
IR Nagaraj	Director, Human Resources and Operations
Prabhat Kumar	Director, Business and Country Relations
CLL Gowda	Global Theme Leader - Crop Improvement
David A Hoisington	Global Theme Leader - Biotechnology
MCS Bantilan	Global Theme Leader - Markets, Policy and Impacts
V Balaji	Head, Knowledge Management and Sharing
Barry I Shapiro	Director, PDMO
CT Hash	Principal Scientist (Breeding)
SN Nigam	Principal Scientist (Breeding)
F Waliyar	Special Assistant-ASP and TIC
Vincent Vadez	Senior Scientist-Plant Physiology
KK Sharma	Principal Scientist (Cell Biology)
J Kashiwagi	Associate Scientist-Drought Tolerance
S P Wani	Principal Scientist – Watersheds
H D Upadhyaya	Principal Scientist (Genetic Resources)
P Lava Kumar	Scientist-Virology
ICRISAT - Lilongwe, Malawi	
Moses Siambi	Senior Scientist-Agronomy and Seed Production, & Country Rep
ES Monyo	Principal Scientist (Breeding)
JD Alumira	Associate Scientist-Impact Assessment
Ms Janneke Verheijen	Associate Professional Officer (Sociology)
Moses Osiru	Associate Professional Officer (Groundnut Pathology)
ICRISAT - Niamey, Niger	
S Koala	Director, WCA
M Diolombi	Regional Finance Officer and Administrator
B Gerard	Senior Scientist
D Pasternak	Principal Scientist- Desert Margin Issues
R Tabo	Assistant Reg Director-WCA, and Principal Scientist (Agronomy)
Jupiter Ndjeunga	Senior Scientist-Economics
Bettina Haussmann	Senior Scientist-Pearl Millet Breeding
Lennart Woltering	Associate Professional Officer (Water Management)
ICRISAT - Bamako, Mali	
BR Ntare	Principal Scientist (Breeding) and Country Representative
EW Rattunde	Principal Scientist (Sorghum Breeding and Genetic Resources)
HFW Rattunde	Principal Scientist (Sorghum Breeding and Genetic Resources)
Margret Loeffen	Associate Professional Officer (Socioeconomics)

Name	Title
Tom van Mourik	Associate Professional Officer (Agronomy-Striga)
M Smit	Associate Professional Officer (Human Nutrition)
ICRISAT- Bulawayo, Zimbabwe	
Isaac J Minde	Senior Scientist (Economics) and Country Rep
SJ Twomlow	Global Theme Leader - Agroecosystems
JP Dimes	Senior Scientist (Farming Systems Modelling)
Andre F van Rooyen	Coordinator (Desert Margins), Zimbabwe
Paul Belder	Associate Professional Officer (Dryland Agrohydrology)
ICRISAT - Nairobi, Kenya	
SN Silim	Director, ESA
RB Jones	Assistant Regional Director, ESA
D Kiambi	Project Coordinator-Sorghum Striga
Peter Cooper	Principal Scientist
Mary A Mgonja	Principal Scientist (Breeding)
B Shiferaw	Senior Scientist-Resource and Development Economics
Susanna M de Villiers	Regional Scientist-Legume Cell Biology
REGIONAL STAFF	
Barnabas N Mitaru	Regional Coordinator, ECARSAM, Kenya
N Hatibu	Regional Coordinator, SWMnet, Kenya
Bancy Mbura Mati	Regional Facilitator-IMAWESA, Kenya
Githiri Stephen Mwangi	Regional Scientist, Kenya
Mary W K Mburu	Project Manager-Lucrative Legumes Project, Kenya
Philip Ndungu	Regional Administrator, ESA
Swathi Sridharan	Editor-ESA, Zimbabwe
SPECIAL PROJECT SCIENTISTS	
Carlos E Dominquez Otero	Seed Systems Specialist & Project Manager, and Country Rep Mozambique
JVDK Kumar Rao	Special Project Scientist, Patancheru, India
GV Ranga Rao	Special Project Scientist - IPM, Patancheru, India
K P C Rao	Special Project Scientist, Nairobi, Kenya
S Senthilvel	Special Project Scientist, Patancheru, India
T Nepolean	Special Project Scientist, Patancheru, India
Belum VS Reddy	Principal Scientist (Breeding), India
KN Rai	Principal Scientist (Breeding), India
TN Menon	Internal Auditor
HC Sharma	Principal Scientist (Entomology), India
Suresh Pande	Principal Scientist (Pathology), India
KPC Rao	Principal Scientist (Village Level Studies)
K B Saxena	Principal Scientist (Breeding), India
Subhash Chandra	Principal Scientist (Statistics), India
Vanamala Anjaiah	Special Project Scientist, India
Jayashree Balaji	Scientist-Bioinformatics, India
S Marimuthu	Scientist (Agronomy), India
Ch Srinivasa Rao	Scientist (Soil Science), India

Name	Title
Ashok Alur	Project Coordinator-CFC, India
AVR Kesava Rao	Scientist (Agrometeorology), India
Rosana P Mula	Special Project Scientist (Post Doctoral), India
Mark D Winslow	Marketing Specialist, PDMO, India
Utpal Bhadra	Adjunct Scientist, CCMB
O Smith	Principal Scientist (from 1 Feb 07)
POST DOCTORAL FELLOWS	
Eastonce Gwata	Post Doctoral Fellow, Kenya
Lewis Hove	Post Doctoral Fellow, Zimbabwe
Kizito Mazvimavi	Post Doctoral Fellow, Zimbabwe
Sabine Homann	Post Doctoral Fellow, Zimbabwe
Albert Nikiema	Post Doctoral Fellow, Niger
HIRED BY OTHERS - OTHER CG STAFF	
Helge Gallinger	Head Teacher, International School of Hyderabad
Michael Blummel	Scientist (Ruminant Nutrition), ILRI, Patancheru, India
B Clerget	CIRAD, Bamako, Mali
B Sagnard	CIRAD, Bamako, Mali
C Longeley	ODA, Nairobi, Kenya
Peter G Bezkorowajnyj	Scientist, ILRI, Patancheru, India
William Thorpe	Special Project Scientist, ILRI, New Delhi
Madar Samad	Theme Leader, IWMI
Celio Mattia	Researcher, (APO) IWMI
Biksham Gujja	Special Project Scientist, WWF
MD Gupta	Suri Sehgal Foundation
Sarathchandra G Ilangantileke	Postharvest Specialist, CIP, New Delhi
Upali Amarasinghe	Senior Statistician, IWMI, New Delhi
Deepa Joshi	Researcher (Gender and Livelihoods)
Priyanie Amerasinghe	Researcher (Bio-medical Science)
Robert Simmons	Soil Scientist, IWMI, Patancheru
Iain Alexander Wright	Reg Rep (Asia), ILRI, Delhi
Nils Teufel	Scientist (Post Doctoral) ILRI, Delhi
ML Chadha	Principal Scientist, AVRDC

Scientific and Managerial Group

Name	Title
ICRISAT Headquarters, Patancheru	
Prabhakar Pathak	Principal Scientist (Soil & Water Mgt)
Piara Singh	Principal Scientist (Soil Science)
AJ Rama Rao	Senior Manager, Human Resources
OP Rupela	Principal Scientist (Microbiology)
Lydia Flynn	Editor in Chief
P Parthasarathy Rao	Senior Scientist
M Prabhakar Reddy	Head, Farm Services
C Geetha	Senior Manager, DG's Office
T Kulashekar	Senior Manager, PSD
K Jagannadham	Senior Manager - Transport
Nalini Mallikarjuna	Senior Scientist (Cell Biology)
NSS Prasad	Head, Farm and Engineering Services
KRC Bose	Manager, Engineering Services
S Sethuraman	Head, Financial Services
S Srinivas	Head-Library & Docn. Services
C Narasimha Reddy	Senior Manager - Medical Services
K Ravishankar	Head, Housing & Food Services
PM Gaur	Principal Scientist (Breeding)
TD Peter	Head, Security Services
TK Sreedevi	Scientist-Watershed Development
Pradyut J Modi	Manager, ISU
Aruna Rupakula	Scientist (Breeding)
Ashish Srivastava	Senior Scientist (Maize Breeding, CIMMYT)
Rajeev K Varshney	Senior Scientist (AGL)
L Krishnamurty	Scientist (Plant Physiology)
Madhavi Latha	Scientist (Pigeonpea Breeding)
M Karuppan Chetty	Manager, ABI
Abdul Rahman Ilyas	COO, ASP
Ranjana Bhattacharjee	Scientist-Pearl Millet Breeding
Rajan Sharma	Scientist-Cereals Pathology
ICRISAT, Delhi	
PN Mathur	Principal Scientist (IPGRI)
ICRISAT - Bamako, Mali	
PCS Traore	Manager, GIS

Visiting Scientists **Consultants**

Name		Name
ICRISAT Headquarters, Patancheru		**ICRISAT Headquarters, Patancheru**
Satish K Sain		C Vineela
Emmanuel H D'Silva		KS Anandaiah
S Nedumaran		M Peter Vijay
TP Mathur		Pooja Bhatnagar-Mathur
RC Sachan		V Ratna Reddy
TS Vamshidhar Reddy		Y Ramakrishna
BK Rajashekar Rao		John L Pender
KV Padmaja		Chetan Sharma
Hameeda Bee		RG Henzell
K Sai Vishnu Priya		Chitendra Kumar
V Arunachalam		Bhupendra Bhatia
Suresh Kumar Yadav		DK Mehta
Rakesh Kumar Srivastava		Director, NCAP (Attn: Dr P K Joshi)
Mamta Sharma		
Pratap Singh Birthal		**ICRISAT Niamey, Niger**
Surya Gunjal		Siaka S Boureima
Santosh P Deshpande		
Mukund Gorakshkar		
KL Sahrawat		
SN Singh		
Mukesh Kumar Dhillon		
Ch Ravinder Reddy		
FR Bidinger		
V Vinod Goud		
G Alexander		
K Krishnappa		
Ruchi Srivastava		
Farhet Ahmad Shaheen		
ICRISAT- Bulawayo, Zimbabwe		
Willis Gwenzi		
David Love		
ICRISAT- Nairobi, Kenya		
Julius Juma Okello		

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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