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Document presented for Agenda Item 9:
CRP 3.6 Proposal - Dryland Cereals

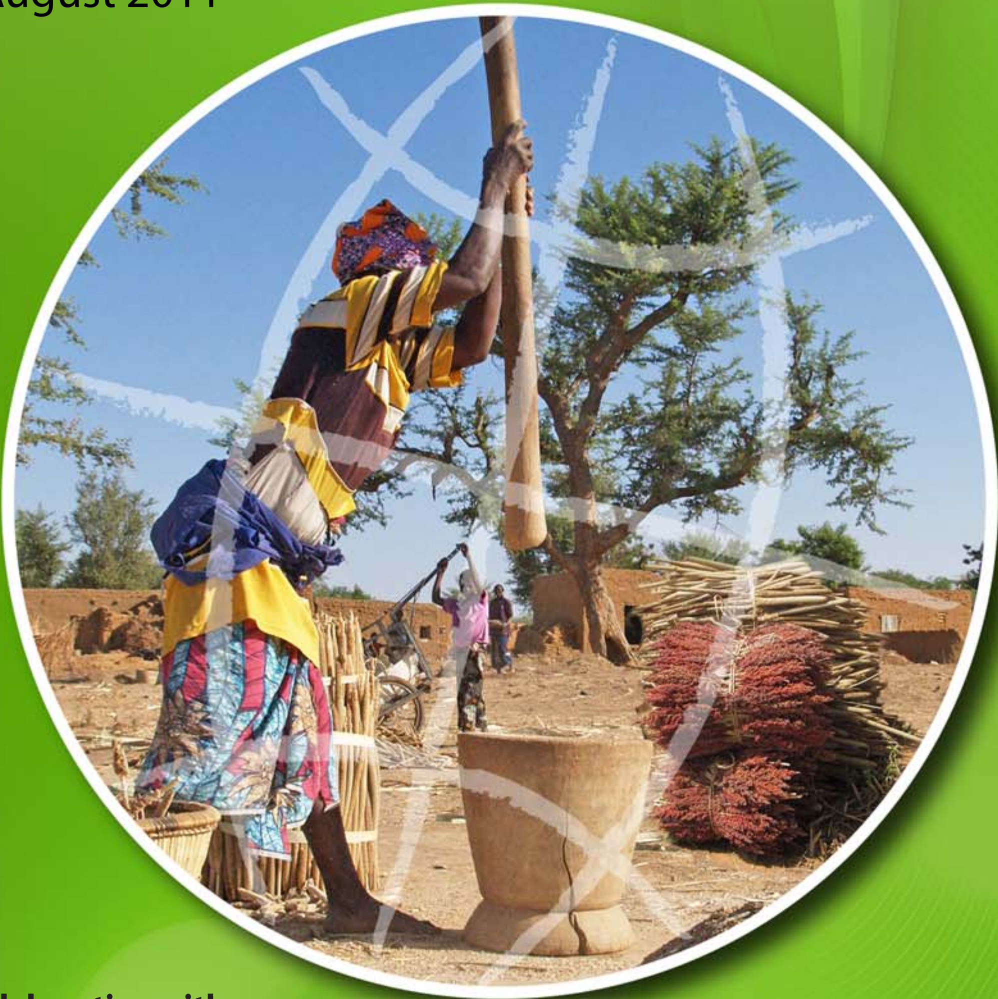
<u>Submitted by</u>:
ICRISAT

DRYLAND CEREALS

A global alliance for improving food security, nutrition and economic growth for the world's most vulnerable poor

A CGIAR Research Program submitted by
ICRISAT and ICARDA to the CGIAR Consortium Board

15 August 2011



In collaboration with
Generation Challenge Program (GCP)
Indian Council of Agricultural Research (ICAR)
Iranian Agricultural Research, Education and Extension Organization (AREEO)
Institut de Recherche pour le Développement (IRD)
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)
Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL)
National agricultural research and extension systems in Africa and Asia
National and international public and private sector research and development partners

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FOREWORD

The CGIAR Research Program on DRYLAND CEREALS (CRP 3.6) presented in this document is designed to achieve sustainable, farm-level productivity increases of the major dryland cereal crops now grown in some of the world's harshest environments. More than a billion of the Earth's poorest inhabitants live in these areas, and they have very few livelihood alternatives to growing dryland crops (often in dynamic crop-livestock systems). While considerable progress has been made over the past four decades to meet smallholder farmer needs for more robust dryland crop varieties, much more can and must be done to reduce rural poverty, ensure food security and enhance environmental sustainability in dryland areas. DRYLAND CEREALS comprises a unique international effort to combine the experience and resources of two CGIAR Centers with those of France, India, Iran, the USA and many other partners to better coordinate and expedite the research-for-development (R4D) efforts related to four key dryland cereal crops – barley, finger millet, pearl millet and sorghum – which are now grown on well over 100 million hectares across Africa, Asia and the Americas.

Our overriding goal is to achieve farm-level impacts, primarily through higher and more stable dryland crop productivity on smallholder farms in Africa and Asia that will increase incomes and reduce rural poverty, increase food security, improve nutrition, and help reduce adverse environmental impacts (especially in dryland crop-livestock systems). Our R4D efforts and outputs will be demand driven, synergistic, and will feature two-way linkages to the work being done in other key CRPs – especially: CRP 1.1 (Integrated agricultural production systems for dry areas); CRP 2 (Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor); CRP 3.1 (WHEAT: Global alliance for improving food security and the livelihoods of resource poor in the developing world); CRP 3.2 (MAIZE: Global alliance for improving food security and the livelihoods of resource-poor in the developing world); CRP 3.3 (GRiSP: a global rice science partnership); CRP 3.5 (Grain Legumes); CRP 3.7 (Sustainable staple food productivity increase for global food security: livestock and fish); CRP 4 (Agriculture for improved nutrition and health); CRP 5 (Durable solutions for water scarcity and land and ecosystem degradation); and CRP 7 (Climate change, agriculture and food security), as well as other major donor-funded initiatives.

The comparative advantages of the partners involved in DRYLAND CEREALS will be a driving force for their inclusion in this initiative, as will a demonstrated commitment to a shared vision of success, achievement of the Program's strategic objectives, and a willingness to work in new, more progressive and ground-breaking ways. In particular, we know that this initiative will require not only greater innovation and investment, but also new approaches that foster improved cooperation and coordination regardless of institutional affiliation. We see the CRP framework as a means to that end, and as a way to capitalize on potential synergies and realize new efficiencies in research and development on behalf of the poor.

We believe that the success of DRYLAND CEREALS will dramatically improve the livelihoods, food security, nutrition, and health status of millions of our fellow citizens. For us, failure is not an option. We hereby commit ourselves, and our institutions, to the collective actions and investments required to achieve a better, more prosperous and food-secure future for millions of people living in dryland areas – people who struggle daily simply to survive under unforgiving agricultural conditions.

William Dar, Director General, ICRISAT

Mahmoud Solh, Director General, ICARDA

ACKNOWLEDGMENTS

The development of the DRYLAND CEREALS Research Program and this document is due to the hard work, commitment and dedication of the many scientists from national programs and the international centers that contributed to its development. Throughout, they shared openly and freely in a spirit of common cause. The development of the initial submission in September 2010 evolved into a concrete research-for-development (R4D) program aimed at resolving longstanding problems and providing new pathways to improved livelihoods, better health, and greater sustainability for farmers and consumers in the dryland areas of developing countries in Africa and Asia. The willingness of those involved in developing the September 2010 submission to conduct business in new ways and with greater cohesiveness was an early indication of a collective desire to break new ground.

Many of those involved in developing our first submission have been involved in the continuing effort to further refine and develop the CRP. Helpful reviews of the September 2010 and May 2011 submissions guided fresh thinking and the further development of DRYLAND CEREALS, and those inputs are reflected in this submission of the proposal, submitted to the CGIAR Consortium Board on August 15, 2011.

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ACRONYMS

AAFEX	Association Afrique Agro Export, Senegal
AAFRD	Alberta Agriculture, Food and Rural Development
AARD	Alberta Agriculture and Rural Development, Canada
AARINENA	Association of Agricultural Research Institutions in the Near East and North Africa
ABRII	Agricultural Biotechnology Research Institute of Iran
ACIAR	Australian Centre for International Agricultural Research, Australia
ACTIA	Association de Coordination Technique pour l'Industrie Agro-alimentaire, France
AE	Adult equivalents
AFD	Agence Francaise de Developpement France
AFTER	African Food Tradition Revisited by Research
AGRA	Alliance for a Green Revolution in Africa
AIP	Agribusiness and Innovation Platform, ICRISAT
AIRD	Agence inter-établissements de recherche pour le développement, France
AIs	Adequate Intakes
AMEDD	Association Malienne d'Eveil au Développement Durable, Mali
AMPROSOR	Sorghum Producers Association, Nicaragua
AMSP	Association Minim Song Panga, Burkina Faso
ANRRO	Agricultural and Natural Resources Research Organization
AOPP	Association des Organisations Professionnelles Paysannes, Mali
APAARI	Asia-Pacific Association of Agricultural Research Institutions
APCAEM	The United Nations Asian and Pacific Centre for Agricultural Engineering and Machinery
ARC	Agricultural Research Center, Libya
ARCAD	Agropolis Resource Center for Crop Conservation Adapatation and Diversity
AREA	Agricultural Research and Extension Authority, Yemen
AREEO	Iranian Agricultural Research, Education and Extension Organization, Iran
ARIs	Advanced Research Institutes
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
BBSRC	Biotechnology and Biological Sciences Research Council, UK
BC	Benefit Cost
BCNAM	Backcross nested association mapping
BDM	Becker, DeGroot and Marschak
BMR	Brown mid rib
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit Und Entwicklung, Germany
BSGM	Barley stem gall midge
BYDV	Barley yellow dwarf virus
CABI	Centre for Agricultural Bioscience International
CAC	Central Asia and the Caucasus
CAPIs	computer assisted processing instruments
CBARDP	Community Based Agriculture and Rural Development Programme
CBBC	Centre de Biotechnologie de Borj-Cédria
CBFFS	Cluster-based farmer field schools
CBOs	Community-based Organizations
CBS	Centre de Biotechnology of Sfax
CENTA	Centro Nacional de Tecnificación Agrícola, El Salvador
CERRA	Centre Régional de Recherche Agronomique, Maradi, Niger
CFTRI	Central Food Technological Research Institute, India
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture, Colombia
CIMMYT	International Maize and Wheat Improvement Centre, Mexico
CIPHET	Central Institute of Post Harvest Engineering and Technology, India
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France
CMS	Cytoplasmic male sterility
CNIAB	National Center for Agricultural Research and Biotechnology, Nicaragua
CNOP	Coordination nationale des organisations paysannes du Mali
CNRS	Centre National de la Recherche Scientifique, France
COMESA	Common Market for Eastern and Southern Africa
CORAF	West and Central African Council for Agricultural Research and Development
CREAF	Le Centre de Recherches Environnementales, Agricoles et de Formation, Kamboinsé
CRP	CGIAR Research Program
CRRA	Centre Regional de Recherche Agronomique, Mali
CRSPs	Collaborative Research Support Programs
CSIR	Council for Scientific and Industrial Research, South Africa

CSOs	Civil Society Organizations
CTA	Technical Centre for Agricultural and Rural Cooperation, The Netherlands
CVM	Contingent valuation method
CWANA	Central and West Asia and North Africa
DARE	Department of Agricultural Research and Education, Ministry of Agriculture, Govt of India
DARI	Dryland Agricultural Research Institute, Iran
DC	Dryland cereals
DEEDI	Department of Employment, Economic Development and Innovation, Australia
DICTA	Directorate of Agricultural Science and Technology, Honduras
DNA	Deoxyribonucleic Acid
DRC	Domestic resource cost
DRD	Department of Research and Development, Ministry of Agriculture, Tanzania
DSR	Directorate of Sorghum Research, India
DWR	Directorate of Wheat Research, India
EAR	Estimated nutrient requirement
EC	European Commission
ECARSAM	Eastern and Central Africa Regional Sorghum and Millet Network
ECO	Economic Cooperation Organization
ECOWAS	Economic Community of West African States
EDPs	Entrepreneur development programs
EECA	East Europe and Central Asia
EIAR	Ethiopian Institute of Agricultural Research, Ethiopia
EISMV	Ecole Inter-Etats des Sciences et Médecine Vétérinaires de Dakar, Senegal
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária, Brazil
ENSAI	National School of Agro-Industrial Sciences, Cameroon
EPC	Effective protection coefficient
ESA	Eastern and Southern Africa
ESB	Escola Superior de Biotecnologia, Portugal
ESRI	Environmental Systems Research Institute Inc., USA
EU	European Union
FAAU	Faculture of Agriculture, Alexandria University, Egypt
FAO	Food and Agriculture Organization
FCI	Food Corporation of India
FFEM	Fédération française d’économie montagnarde
FFS	Farmers Field Schools
FIGS	Focused Identification of Germplasm Strategy
FIPs	Farm inputs promotions
FOFIFA	Centre National pour le Developpement Rural, Madagascar
FONTAGRO	Regional Fund for Agricultural Technology, Latin America
FOs	Farmer Organizations

FPU	Food processing unit
FRI	Food Research Institute, Ghana
FTE	Full time equivalent
GBS	Genotyping by sequencing
GCDT	Global Crop Diversity Trust
GCP	CGIAR Generation Challenge Program
GI	Glycaemic Index
GIS	Geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit, Germany
GPG	Global public goods
GRIN-GLOBAL	Global Genetic Resources Information Management System
GRiSP	Global Rice Science Partnership
GS	Genomic Selection
GWS	Genome-wide selection
GxE	Gene by Environment
HOPE	Harnessing Opportunities for Productivity Enhancement
HPLC	High performance liquid chromatographic
HPR	Host plant resistance
IAR	Institute for Agricultural Research, Nigeria
IARC	International Agricultural Research Center
IASA	Impulsora Agricola, S.A. de C.V., Mexico
IBP	Integrated Breeding Platform
ICAMEX	Agricultural, Forestry and Fisheries Research and Training Institute, Mexico
ICAR	Indian Council of Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas
ICAR-DWR	Indian Council of Agricultural Research - Directorate of Wheat Research
ICM	Integrated crop management
ICP	Inductively coupled plasma
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics, India
ICRW	International Center for Research on Women, USA
ICT	Information and communication technology
ICTA	Imperial College of Tropical Agriculture, Trinidad
IDIAP	Institute of Agricultural Research of Panama
IDM	Integrated Disease Management
IDRC	International Development Research Centre, Canada
IER	Institute for Economic Research, Mali
IFAD	International Fund for Agricultural Development
IFAD-CBARDP	International Fund for Agricultural Development and Community Based Agricultural and Rural Development Project, Nigeria
IFAD-PDRD	IFAD-Programme de Développement Rural Durable, Burkina Faso

IFAD-PPILDA	IFAD- Project for the Promotion of Local Initiative for Development in Aguié, Niger
IFDC	International Fertilizer Development Corporation, USA
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH, Germany
IFPRI	International Food Policy Research Institute, USA
IGNRM	Integrated Genetic and Natural Resource Management
IIAM	Institute of Agricultural Research for Mozambique, Mozambique
IICEM	Integrated Initiatives for Economic Growth in Mali
IICPT	Indian Institute of Crop Processing Technology, India
ILRI	International Livestock Research Institute, Kenya
IMPACT	International Model for Policy Analysis and Commodity Trade
INAT	Institute National Agronomique de Tunisia
INERA	Institut National de l'Environnement et Recherche Agricole, Burkina Faso
INRA	Institute National de La Recherché Agronomique, Morocco
INRAB	Institut national de recherche agronomique du Bénin, Burkina Faso
INRAN	National Agricultural Research Institute, Niger
INRAT	National Agricultural Research Institute of Tunisia
INSAH	Institut du Sahel, Mali
INSTAPA	Novel staple food-based strategies to improve micronutrient status for better health and development in sub-Saharan Africa
INTA	National Institute for Agricultural Technology, Argentina
INTSORMIL	Sorghum, Millet and Other Grains Cooperative Research Support Program
IP	Intellectual Property
IPK	Leibniz Institute of Plant Genetics and Crop Plant Research, Germany
IPM	Integrated Pest Management
IPR	Intellectual Property Rights
IRAG	Guinean Institute for Agricultural Research
IRD	Institut de Recherche et Développement, France
IRRI	International Rice Research Institute, Philippines
IRSAT	Institut de Recherche en Sciences Appliquées et Technologies, Burkino Faso
ISF	International Seed Federation, Switzerland
ISFM	Integrated Soil Fertility Management
ISHS	International Society for Horticultural Science
ISM	Integrated soil management
ISRA	Senegalese Institute for Agricultural Research, Senegal
ISTA	International Seed Testing Association
ITA	Institut de Technologie Alimentaire, Dakar, Senegal
ITPGRFA	International Treaty on Plant Genetic Resources for Food and Agriculture
JIRCAS	Japan International Research Center for Agricultural Sciences, Japan
KARI	Kenya Agricultural Research Institute, Kenya
KM	Knowledge Management
KSFA	Karnataka State Farmers' Association, India
LABOSEM	Directeur du Laboratoire de Semences, Mali
LCRI	Lake Chad Research Institute, Nigeria
LD	Linkage disequilibrium
LDC	Least developed countries
LDL	Low-Density Lipoprotein
LIFDCs	Low Income Food Deficit Countries
M&E	Monitoring and Evaluation
MAB	Marker-assisted breeding
MAPI	Marker-assisted population improvement
MARS	Marker-assisted recurrent selection
MAS	Marker-assisted selection
MAU	Marathwada Agricultural University, India
ME&L	Monitoring, evaluating and learning
MENA	Middle East and North Africa
MET	Multi-Environment Trials
MIS	Market information services
MOSA	Maltería Oriental S.A., Uruguay
MPKV	Mahatma Phule Krishi Vidyapeeth in Rahuri, India
MSP	Minimum support price
MTA	Material Transfer Agreement
NACA	Network of Aquaculture Centres in Asia-Pacific
NARES	National Agricultural Research and Extension Systems
NARI	National Agricultural Research Institute, Eritrea
NARO	National Agricultural Research Organization, Uganda
NARS	National agricultural research system
NBPGR	National Bureau of Plant Genetic Resources, India
NCARE	National Center for Agricultural Research and Extension, Jordan
NGB	The Nordic Gene Bank
NGOs	Non-Governmental Organizations
NGS	New generation sequencing
NIN	National Institute of Nutrition, India
NIRS	Near-Infrared Spectroscopy
NPK	Nitrogen, phosphorus and potassium
NRC	National Research Centre, Egypt
NRI	Natural Resources Institute, United Kingdom
NRM	Natural Resource Management

OECD	Organization for Economic Cooperation and Development
OPVs	Open-Pollinated Varieties
ORAC	Oxygen radical absorbance capacity
P4P	Purchase for Progress, World Food Program
PAM	Policy Analysis Matrix
PASS	AGRA's Program in Africa's Seed Systems
PDRD	Programme De Developpement Rural Durable
PIA	Program Implementation Agreement
PMG	Producer marketing groups
PPILDA	Projet de Promotion des Innovations Locales de Developpement Agricole
PRA	Participatory Rural Appraisal
PRGA	Participatory Research and Gender Analysis
PROMISO	Promoting Pearl Millet and Sorghum Production
QTL	Quantitative Trait Loci
R4D	Research-for-Development
RDAs	Recommended Dietary Allowances
ReSAKKS	Regional Strategic Analysis and Knowledge Support System
RMPs	Random mating populations
RMT	Research Management Team
RNIs	Recommended Nutrient Intakes
RVA	Rapid Visco Analyser
RWA	Russian wheat aphid
SA	South Asia
SAARC	South Asian Association for Regional Cooperation
SADC	Southern African Development Community
SARI	The Savannah Agriculture Research Institute, Ghana
SAT	Semi-Arid Tropics
SC	Steering Committee
SCRI	Scottish Crop Research Institute, UK
SHGs	Self-help groups
SINGER	CGIAR System-wide Information Network for Genetic Resources
SLOs	CGIAR System Level Outcomes
SMEs	Small and Medium Enterprises
SMIP	Sorghum and Millet Improvement Program
SMTA	Standard Material Transfer Agreement
SNP	Single nucleotide polymorphism
SO	Strategic objective
SOLIBAM	Strategies for Organic and Low-input Integrated Breeding and Management
SPES	Spread European Safety, Italy
SPII	Seed and Plant Improvement Institute, Iran
SRF	Strategic and Results Framework
SSA	Sub-Saharan Africa
SSNM	Site-specific nutrient management
UAC	University of Abomey Calavi, Benin
UACT	Union des Agriculteurs de Cercle de Tominian/Union of Farmers of the Circle of Tominia
UCAD	Ecole Supérieure Polytechnique / Cheikh Anta Diop University of Dakar, Senegal
UGCPA/BM	Union de Groupement pour la commercialisation des Produits Agricole, Boucle du Mouhoun, Burkina Faso
UGPCA	Union des groupement des producteurs pour la commercialisation agricole, Burkina Faso
ULPC	Union Locale des Producteurs de Cereales, Mali
UN	United Nations
UNA	Universidad Nacional Agraria en Managua, Nicaragua
UN-CAPSA	United Nations – Centre for Alleviation of Poverty through Sustainable Agriculture
UNSCPC	Union Nationale des Sociétés Coopératives de Producteurs de Coton Producteurs, Mali
UNZA	University of Zambia, Zambia
UPOV	International Union for the Protection of New Varieties of Plants
USAID	United States Agency for International Development
USDA	United States Department of Agriculture, USA
UT	Antananarivo University, Madagascar
VAM	Vesicular-arbuscular mycorrhiza
VOP	Value of production
VPD	Vapour pressure deficit
WA	West Africa
WCA	West and Central Africa
WFP	World Food Programme
WTP	Willingness to pay
WUE	Water use efficiency
XRF	X-ray Fluorescence

Executive Summary

The CGIAR has long been one of the few organizations that have paid attention to the dryland agro-ecological zones found in many developing countries around the world. That attention notwithstanding, at least half of the more than 1 billion people living in these areas struggle to survive on only US$ 1.25/day or less, usually from smallholder subsistence agriculture. Both Asia and Africa contain deep pockets of poverty that are closely aligned to where the drylands are, and while much has been done since the advent of the CGIAR to improve the livelihoods of families living in these areas, much more needs to be accomplished.

Why a Dryland Cereals CRP?

This CGIAR Research Program (CRP 3.6 DRYLAND CEREALS) is focused exclusively on the drylands of Asia and Africa, and primarily on improving the productivity and profitability of four major cereal crops commonly grown there – barley, finger millet, pearl millet and sorghum. Based on recent projections using IFPRI's IMPACT model, the aggregate demand for these crops will increase significantly by 2020 in our target regions and countries, relative to the model's year 2000 baseline (Table 1). The demand for barley will rise by about 44%, millets (mainly pearl millet) by 39%, and sorghum by 48%, all driven largely by population growth in our target regions and a lack of alternative crops that can grow there. At the same time, because dryland cereals are already being grown in very harsh environments, area expansion as a means for meeting increasing demand is not feasible. Moreover, according to recent studies even these crops will be adversely affected by climate change. In Africa, for example, average yields of sorghum and millets are predicted to fall by about 17% by 2050 due mainly to rising temperatures. We know less about the probable effects of climate change on barley, but it is safe to say that its productivity will also be affected over time.

DRYLAND CEREALS partners believe that strong and sustained efforts are urgently needed to deal with these changing realities. There are three primary interventions that we will make: 1) we will produce well-adapted, higher yielding varieties with better disease resistance and tolerance to abiotic stresses; 2) we will develop improved crop management technologies that are suited to dryland ecologies and can get more out of existing and improved varieties, i.e., reduce the gaps between on-station and on-farm yields; and 3) we will identify and encourage the implementation of more efficient and effective systems for getting improved technologies into the hands of smallholder farmers. These objectives form the core of CRP 3.6. In addition, for us to accomplish these in a timely and efficient manner and to keep our efforts and priorities properly focused, we will gather and analyze gender-disaggregated data and information about our specific target areas, and we will exploit state-of-the-art genomic tools to improve breeding efficiency. Moreover, in order to help smallholder farmers – especially women – to improve their livelihoods, we will identify effective ways to reduce post-harvest losses, as well as new opportunities for processing and marketing dryland cereal products.

Dryland cereals are important crops. Taken together, the farm gate value of barley, finger millet, pearl millet and sorghum produced in Low Income Food Deficit Countries (LIFDCs) is US$ 27.3 billion (Table 2). Population growth is a primary driver of demand, with at least 40% of production being consumed directly by the poor as food in various forms. However, about 50% of the demand for dryland cereals is related to sustaining livestock (providing feed and fodder) in integrated crop-livestock systems. In addition, urban consumers are rediscovering the health benefits that come with eating traditional foods and newer processed products prepared using dryland cereals. Moreover, a growing portion of these crops is being marketed for various industrial uses (e.g. malting, sweet syrups and ethanol), which is providing increasing amounts of cash income to smallholder farmers. Given their substantial economic value and the importance of these cereals as a mainstay for the hundreds of millions living in our target areas, relatively limited resources have been and continue to be allocated to them.

WHY WORK ON THESE CROPS UNDER A SINGLE CRP?

In addition to these shared demand drivers, other factors make it both more efficient and more effective to focus research-for-development (R4D) initiatives on dryland cereals under a single CRP. All four crops, for example, can be improved using similar breeding and development approaches, e.g. participatory breeding, the use of genomic-based methods, and the exploitation of heterosis. Working on them together also gives rise to a critical mass in research aimed at achieving development impacts. Moreover, there are common researchable issues associated with these crops, such as:

- Understanding the nature of tolerance these crops share towards drought, high temperatures and low soil fertility;
- Determining the potential for increasing total biomass production and quality for use as fodder;
- Development of alternative weed management strategies given the limited availability of labor in sparsely populated dryland areas;
- Addressing similar constraints faced by these crops regarding seed delivery systems and market access; and
- The importance of improving post-harvest processing for better shelf life and nutritional value.

DRYLAND CEREALS R4D efforts and outputs are demand driven, with smallholder farmers heavily involved in identifying preferred traits and driving participatory breeding programs. Barley, finger millet, pearl millet and sorghum all possess substantial genetic yield stability under adverse production conditions and high levels of water and nutrient use efficiency, which indicates considerable potential for reducing production risks for resource-poor dryland smallholders. They have a robust genetic tolerance for drought, high temperatures and soil salinity, as well as strong tolerance for or resistance to pests and diseases. Moreover, these crops are efficient in the use of water and fertilizer, especially important under resource-limited conditions. We must capitalize on the opportunity to capture these inherent advantages. These crops have high levels of important micronutrients (zinc, iron, calcium) and other nutritive benefits, and all are consumed primarily where they are produced, indicating high potential for direct impacts on livelihoods. All four crops are used in multiple ways – directly for food, as very important sources of feed and fodder, and increasingly for industrial purposes – and women play a prominent role in their cultivation, processing and preparation, which opens opportunities to directly improve their wellbeing.

PROGRAM INNOVATIONS

In addition to doing business differently, the business we will be doing is itself different. We believe that combining the creative talents of a wider range of partners oriented towards a shared vision and set of strategic objectives will lead to new innovations in DRYLAND CEREALS R4D. Specific major innovations include the following (for details, see Program Innovations Section, as well as each Strategic Objective):

- Using whole genome sequencing of the dryland cereals to identify new genes and markers for breeding;
- Accessing genetic resources, creating phenotypic databases, and collecting geospatial information to exploit genetic diversity;
- Promoting integrated breeding platforms and the application of genomic-based technologies;
- Tapping heterosis to boost yields;
- Developing and disseminating multi-purpose varieties; and
- Improving the quality and shelf life of dryland cereal products.

VISION OF SUCCESS

By 2020, we will achieve a sustainable 15% increase in dryland cereal farm-level production on at least 45 million hectares in Africa and Asia. This will be done through a combination of crop improvement research, better agronomic practices, and more effective delivery systems for seed, information and other inputs. At the same time, we will improve grain and stover quality. We project that, by 2020, these improved technologies will be made available to an additional 33 million smallholder farmers in our target regions. Women farmers will be a primary focus of our work. Through their participation, we will ensure that appropriate quality traits are preserved or integrated into new varieties, suitable agronomic practices are developed and promoted, and effective and profitable post-harvest processing and market access options are identified. Rural households will benefit primarily from increased food security and better nutrition, but also from an increase in cumulative net incomes (by 2020) of about US$ 1.5 billion.

DRYLAND CEREALS will increase the stability of productivity (yield per unit area) and production (total availability) of barley, finger millet, pearl millet and sorghum grown in dryland environments. By 2020, the Program will generate at least 150 new varieties that have the traits preferred by smallholder farmers and consumers in target countries. Formal and informal seed sectors (public and private) will be mobilized to produce and disseminate quality seed of improved varieties to target smallholder farmers, with particular attention paid to those who usually face the greatest difficulties in accessing seed and other inputs. The value added from additional grain production alone is expected to reach US$ 1.5 billion by 2020.

A FOCUS ON GENDER

Gender is given a high priority throughout DRYLAND CEREALS. Key considerations include recognition of the role gender plays in growing, harvesting and processing dryland cereals, women farmer-led research and the need for participatory and gender-responsive approaches to the problems of poverty, food security and sustainability. Gender disaggregated roles will be explicitly addressed by each Strategic Objective and related activities and outputs. Gender-differentiated data will be collected to more fully understand the differing roles of men and women; capacity strengthening and technical training will include women in equitable numbers; and technologies will be developed with the aim, not just of reducing drudgery, but opening marketing and income-earning opportunities for women.

STRATEGIC OBJECTIVES AND OUTPUTS

DRYLAND CEREALS is focused primarily on the core competencies of crop improvement (including the use of genetic resources and genomics), cropping systems and post-harvest technologies, with significant efforts in production systems and price, trade and policy areas. Beyond these traditional core competencies, DRYLAND CEREALS also brings expertise and focus to new areas identified in the Strategy and Results Framework (SRF) such as climate change adaptation/mitigation and nutrition and health.

DRYLAND CEREALS is structured around six key Strategic Objectives (SO):

- **SO 1** – **Better targeting of opportunities for technology development and delivery** of dryland cereals to smallholder farmers in Africa and Asia
- **SO 2 – Enhancing the availability and use of genetic diversity, genomics and informatics** to enhance the efficiency of dryland cereal improvement
- **SO 3** – **Developing improved dryland cereal varieties and hybrids** for increased yield, quality and adaptation in smallholder farmers' fields
- **SO 4** – **Developing sustainable crop, pest and disease management options** to capture genetic gains from improved dryland cereal varieties and hybrids

SO 5 – Enhancing effective seed and information systems for better delivery of improved technology packages to smallholder farmers

SO 6 – **Adding post-harvest value and improving market access** of dryland cereals to provide smallholder farmers more benefits from dryland cereals

These Strategic Objectives address a key set of researchable questions or issues of central relevance to dryland cereals, including: their usefulness as sources of genes for stress tolerance for adapting to climate change, and especially our understanding of such tolerance mechanisms; their importance as sources of feed, fodder and straw in the face of the ongoing "livestock revolution"; the potential for achieving sustainable increases in productivity, production and nutritive value on behalf of the poorest of the poor living in highly marginal production environments; and the need to identify effective ways to improve the delivery, availability, and adoption of improved dryland cereal technologies in our target areas and farming systems, as well as viable post-harvest alternatives for adding value and earning additional income through better market access.

Each Strategic Objective comes with a description of its priority activities and impact pathway, the partners that will be involved and what they will contribute, how relevant gender issues will be addressed, the innovations that pertain to the Objective, the outputs that will be produced, the methodologies that will be applied, and key milestones that will demarcate progress.

While all six Strategic Objectives are important in each target region, differing emphasis will be given depending on prevailing challenges and opportunities. In West and Central Africa, for example, more attention will be given to improving the sustainable production of dryland cereals (especially sorghum and pearl millet) under extremely harsh conditions. In South Asia, emphasis will be on improving the profitability of dryland cereals as the demand for feed and fodder increases and new market opportunities open up for farmers. The West Asia/North Africa and eastern and southern Africa regions are more transitional with a broader mix of farmers and opportunities, thus requiring a more balanced emphasis.

CAPACITY STRENGTHENING

Capacity strengthening will be integrated throughout DRYLAND CEREALS. This will include provision of degree and non-degree training, workshops and conferences, and the development of knowledge and distance learning products. Because extension staff and NGOs work at the grassroots level, special efforts will be made to empower them. Our training programs will reflect a return to basics to offset declines in the number of staff trained in conventional breeding, agronomy, pest control, and field techniques. Capacity strengthening will be targeted to enable all actors along the value chain to produce required outputs and achieve desired outcomes in order to impact smallholder farmers

CONTRIBUTIONS TO SYSTEM LEVEL OUTCOMES

DRYLAND CEREALS will contribute to all four of the CGIAR System Level Outcomes – reduced rural poverty, improved food security, improved nutrition and health, and sustainably managed natural resources, though our emphasis will be on the first three of these. Barley, finger millet, pearl millet and sorghum do well in harsh environments, and thus they offer farmers important opportunities for increasing their incomes and improving their livelihoods. Crop residues, especially stover and straw, are increasingly important commodities that increase the overall value of dryland cereals. The demand for processed, value-added dryland cereal products is growing, especially in urban areas, and we will partner with organizations specializing in cereal processing, as well as those designing and producing post-harvest processing equipment. Moreover, there is growing interest in using dryland cereal grains for industrial purposes, especially for malting, which presents additional marketing and income opportunities.

However, these cereals are still consumed primarily on-farm and by the very poorest people. Trapped in subsistence farming, the poorest farm families are very food insecure and often suffer from hunger and malnutrition, especially in the months leading up to harvest. Women and children, who are less empowered within households, normally suffer the most. By improving the production, productivity and nutritional content of dryland cereals (the latter building on existing HarvestPlus and CRP 4 research efforts and partnerships), smallholder farmers who grow them will be able to capture much-needed benefits.

PARTNERS INVOLVED

ICRISAT is the Lead Center for DRYLAND CEREALS, with ICARDA as its CGIAR partner in developing and implementing the CRP. Having said that, DRYLAND CEREALS is a truly global alliance. The CRP will benefit from the leadership and expertise of the CGIAR's Generation Challenge Program (GCP), the Indian Council of Agricultural Research (ICAR), the Iranian Agricultural Research, Education and Extension Organization (AREEO), the L'institut de recherche pour le développement (IRD) and the Centre de coopération internationale en recherché agronomique pour le développement (CIRAD) in France, the USAID-supported Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL), and more than 60 national agricultural research and extension programs in Africa and Asia, 20 advanced research institutes, and 25 NGOs, CSOs, Farmer Organizations and private sector companies (see chapter on Partners and Table 9).

INTERACTIONS WITH OTHER CRPS

DRYLAND CEREALS will link with – and leverage resources, information, partnerships and technologies from – a number of other CRPs (see Table 10). Specifically, DRYLAND CEREALS will:

- Work with CRP 1.1 (Dryland Systems) to better fit optimal dryland cereal production technologies in smallholder mixed farming systems;
- Identify deficiencies in marketing systems and devise mitigation strategies together with CRP 2 (Policies and Markets);
- Exchange information on breeding methodologies, traits and genes with CRP 3.1, 3.2 and 3.3 (WHEAT, MAIZE and GRiSP);
- Optimize cereal-legume systems through collaboration with CRP 3.5 (Grain Legumes);
- Develop more suitable feed and fodder varieties in concert with CRP 3.7 (Livestock);
- Partner with CRP 4 (Health and Nutrition) to improve household nutrition with dryland cereals;
- Contribute to better land- and water-use efficiency together with CRP 5 (Water scarcity and Land degradation); and
- Ensure availability of climate change-ready crops with CRP 7 (Climate Change).

PROJECTED RETURN ON INVESTMENT

DRYLAND CEREALS will increase the average productivity of its target crops by at least 15% by 2020, which will result in an increase in production of about 22 million tons in total grain production by the end of the decade. At current average prices, this additional annual grain production will be worth about US$ 1.5 billion in net income to smallholder farmers. In addition for sorghum, more than 12 million extra tons of fodder will be produced in 2020, also worth an estimated US$ 740 million. These not inconsequential benefits will accrue to an estimated 33 million resource-poor smallholders farming in very harsh and risky production environments, and will have resulted from an average annual investment in R4D activities of US$ 25 million per year.

VISION OF SUCCESS

The CGIAR is one of the few international agricultural research organizations that strive to meet the needs of resource-poor smallholder farmers living in marginal, dryland agro-ecological zones found in many developing countries. About half of the 1.5 billion people now living in these areas (especially those in Sub-Saharan Africa) struggle to survive on US$ 1.25/day or less, usually through smallholder subsistence agriculture. Both Africa and Asia have deep pockets of poverty often located where the drylands are, though because of South Asia's population density the total number of poor living in dryland areas there is about twice that of Africa. While much has been done since the advent of the CG System to improve the livelihoods of families living in dry areas, because of the harsh conditions, challenges remain.

DRYLAND CEREALS is focused on improving the productivity of four of the major cereal crops commonly grown in the dry areas of Asia and Africa – barley, finger millet, pearl millet and sorghum. This effort will rest on partnerships and strengthened capacities in the target regions. DRYLAND CEREALS partners believe that far stronger efforts are urgently needed to address key challenges afflicting an agricultural system vital to the future of hundreds of millions of the most vulnerable people in the world. In many places, population pressure and the need for agricultural intensification have brought dryland cereal production systems under increasing stress. Poverty, food insecurity and environmental degradation are making the situation worse.

VISION OF SUCCESS

The overall vision of success for DRYLAND CEREALS is straightforward:

> *By 2020, we will achieve a sustainable 15% increase in dryland cereal farm-level production on at least 45 million hectares in Africa and Asia. This will be done through a combination of crop improvement research, better agronomic practices, and more effective delivery systems for seed, information and other inputs. At the same time, we will improve grain and stover quality. We project that, by 2020, these improved technologies will be made available to an additional 33 million smallholder farmers in our target regions. Women farmers will be a primary focus of our work. Through their participation, we will ensure that appropriate quality traits are preserved or integrated into new varieties, suitable agronomic practices are developed and promoted, and effective and profitable post-harvest processing and market access options are identified. Rural households will benefit primarily from increased food security and better nutrition, but also from an increase in cumulative net incomes (by 2020) of about US$ 1.5 billion.*

New forms of collaboration and partnership will enable us to make this vision a reality. These will involve the two CGIAR centers that focus significant resources on dryland cereals (ICARDA and ICRISAT); major developed country partners (INTSORMIL in the USA, and CIRAD and IRD in France); the Indian Council for Agricultural Research (ICAR), which has long invested in dryland cereals research and development; the Iranian Agricultural Research, Education and Extension Organization (AREEO), which has been a partner with ICARDA for many years; research partners involved in Generation Challenge Program projects on dryland cereals and integrated plant breeding; national agricultural research and extension systems in our target regions in Africa and Asia; advanced research institutes in the public and private sector; and a wide range of development-oriented NGOs and CBOs working in targeted dryland areas (see DRYLAND CEREALS Partners).

For the first time, organizations working on behalf of dryland cereal smallholder farmers will be coordinating their respective efforts and capitalizing on their comparative advantages in a common cause. Opportunities will be identified for sharing research and testing facilities, as well as results and new knowledge. Smallholder farmers in the drylands will benefit from having one unified source for new options aimed at improving cereal productivity and production. We believe that encouraging such collaboration and realizing potential R4D efficiencies is the fundamental reason behind the CGIAR reform process and, especially the development of CGIAR Research Programs.

CONTRIBUTING TO CGIAR SYSTEM-LEVEL OUTCOMES

We believe that DRYLAND CEREALS will contribute to achieving all four CGIAR System Level Outcomes (SLOs) – reduced rural poverty, improved food security, improved nutrition and health, and sustainably managed natural resources. While our primary contributions will be to the first three of these, because dryland cereals are among the most efficient in using natural resources (water and soil nutrients), improved cereal technologies will also help reduce environmental degradation in dryland areas. We also anticipate that dryland degradation will be reduced through research aimed at optimizing dryland cereal/legume cropping systems, which will enable cereal production to increase without significant additional nitrogen inputs. Our contributions to SLOs 1, 2 and 3 will be more significant, as outlined below.

Reduced rural poverty (System Level Outcome 1)

Over the past two decades, dryland cereals production has increased by more than the area sown to these crops in tropical and subtropical regions. This upward trend, however, is relatively small (0.5-1%/year, depending on the region) and has not been enough to even keep up with population growth, let alone to create marketable surpluses for generating additional income for smallholders (see Appendix 1). Experiments with dryland cereals on research stations, as well on farms, have demonstrated that yields in many dry production ecologies could be two to four times higher using available technologies than those commonly achieved. Some economists argue that the main obstacle to achieving these gains is that smallholders lack reliable markets for their outputs. Why go to the trouble of trying to produce surpluses if there is no way to sell them? Yet such groups as the World Food Programme's Purchase for Progress (P4P) initiative would like to purchase larger quantities of dryland cereal products, but face problems of availability (and the problem is not just a lack of surpluses, but also includes issues relating to product quality, aggregation, and contractual relationships).

DRYLAND CEREALS focus crops hold considerable potential for overcoming production limitations that are common across these difficult environments, and thus they offer farmers important opportunities for increasing their incomes and improving their livelihoods (see Value Proposition, below). Work aimed at increasing profitability and marketing options will be done in close collaboration with CRP 1.1 (Dryland Systems). Assessing production and marketing risks, especially for women farmers, will be a key component, along with identifying options for improving smallholder access to local and regional markets.

Crop residues, especially stover but also straw, are increasingly important commodities that significantly increase the overall value of dryland cereals. The current estimated value of sorghum stover in our target regions, for example, is US$ 13.4 billion. The increasing value of stover has been a prominent trend in Asia (Nordbloom et al., 1983; Kelley et al., 1996), and stover markets are emerging in the drier, more densely populated areas of West Africa. As the demand for livestock and livestock products increases, so too will the importance of fodder and feed. DRYLAND CEREALS will thus focus on increasing the quantity and quality of stover and straw, as well as grain (see Strategic Objective 3), work that will be done together with CRP 3.7 (Livestock).

Home processing of coarse dryland cereals to produce traditional foods is both difficult and time consuming, especially in urban settings. Processed dryland cereal products that are easy and fast to prepare and have good shelf life are increasingly in demand, especially in South Asia. DRYLAND CEREALS will therefore engage with partners specializing in cereal processing, as well as developers and manufacturers of locally adaptable post-harvest processing equipment, with an eye towards meeting the rising urban demand for dryland cereals. Moreover, the growing interest in using dryland cereal grains for industrial purposes, especially for malting and ethanol, presents additional marketing and income opportunities for smallholder producers.

Improving food security (System Level Outcome 2)
More than 650 million of the poorest and most food-insecure people live in dryland areas. To cope with the harsh agro-climatic conditions (low and variable rainfall, high temperatures, poor and saline soils) and especially the high risk of drought, families in the drylands base their farming systems on the world's hardiest and least risky cereals – barley, finger millet, pearl millet and sorghum. These cereals are consumed primarily on-farm and by the very poorest people (depending on the region and crop, as much as 80% is consumed directly). Trapped in subsistence farming, these farm families suffer hunger, especially in the months leading up to the harvest. Women and children, who are less empowered within households, often suffer the most. By improving the productivity and production of these crops in the marginal environments where the poorest people live, they should be able to capture a large share of potential food security benefits. DRYLAND CEREALS will work with these farmers to identify and prioritize their specific preferences – the traits they need and want in new varieties to make them truly useful (see Strategic Objective 1). New genes and traits will be identified through the application of genomics; we will apply the latest crop physiology tools and methodologies to understand the basis for stress tolerance, and better stress-tolerant germplasm with higher and more stable yields will be produced; improved methodologies and tools for genetic improvement in dryland cereals will be developed and applied over the course of the Program (Strategic Objectives 2 and 3); more effective seed and input systems that target smallholder farmers will be established (Strategic Objective 5); and the R4D capacity of Project partners, as well as the practical skills of smallholder farmers in our target countries and regions will be strengthened.

DRYLAND CEREALS will develop new varieties that can better cope with abiotic stresses, such as drought, high temperatures, poor soil fertility and high salinity, by exploiting similar trait physiology. New varieties will also have better resistance to insect pests and diseases. Preferred grain and stalk quality and processing characteristics will be maintained or improved for specific users and agro-ecologies. Smallholder farmers will be heavily involved in shaping the trait combinations of their new varieties to ensure that the process is demand-driven and that new varieties meet farmers' needs for local adaptation and uses. Special emphasis will be given to improved yield stability under the most difficult production conditions in the drylands, which will reduce adoption risks for resource-poor producers. Low-cost agronomic packages will be developed to optimize yields of the new varieties and to increase farmer experimentation with the technologies (Strategic Objective 4). Stronger formal and informal seed and information systems will improve awareness and availability of the new technologies (Strategic Objective 5). Farmer-owned seed businesses or other emerging local seed enterprises in areas where the formal seed system is not well developed will help fill the current seed-marketing gap. Concerted R4D is required to ensure that development organizations, private sector entities, and policy makers are aware of and can capitalize on the opportunities that new varieties can trigger. This is especially important in the area of post-harvest handling, processing and marketing (Strategic Objective 6).

Improving nutrition and health (System Level Outcome 3)
Malnutrition is a challenging and complex issue that requires cooperation among various actors in the agricultural, nutritional, and health arenas (World Bank, 2006). In general, dryland cereals provide important sources of carbohydrates, energy, protein, fiber, calcium, iron, and certain vitamin B complexes, which is especially relevant for poor households in dryland areas that depend on these crops. Finger millet is extraordinarily high in calcium, and eating whole grain barley can regulate blood sugar (i.e., reduce blood glucose response to a meal) for up to 10 hours. Sorghum is a good source of protein, carbohydrates, fiber and energy, as well as iron and potassium. And pearl millet is the highest of these cereals in terms of available protein, energy content and iron.

DRYLAND CEREALS will, mainly as part of Strategic Objective 3 and in close collaboration with CRP 4, produce grain types that have the qualities needed for optimum local processing. HarvestPlus and CRP 4 have identified appropriate methodologies and established the feasibility of increasing the iron and zinc content of dryland cereals. Our main focus will be to ensure that new varieties of dryland cereals at least match the nutritional content of local varieties, i.e., that important nutritional factors are not lost in the breeding and selection process. But biofortification research remains of interest as well, and DRYLAND CEREALS will explore the potential to increase iron and zinc content in the grain. Also of importance is improving such factors as the ease of processing and the shelf life of dryland cereal products. We believe that linking this work with the efforts of HarvestPlus is critical and that the integrated agriculture, nutrition, and health platform envisioned in CRP 4 can generate significant synergies.

THE DRYLAND CEREALS VALUE PROPOSITION

DRYLAND CEREALS will measurably increase the stability of production, productivity (yield per unit area), and production (total availability) of barley, finger millet, pearl millet and sorghum grown in dry environments. Both the productivity of these cereals and their production in the fields of farmers using the new technologies will, by 2020, rise at least 15%. Total grain production in the harsh environments that characterize the drylands of Africa and Asia will rise by about 22 million tons, which will have a total value of about US$ 54 billion. Some 33 million additional farmers will be using improved technologies, and these farmers and their families will have greater food security (defined here as meeting at least 30% of the basic kilocalorie needs of a household from dryland cereals). Farmers will earn a total additional net income in 2020 from dryland cereal grain of about US$ 1.5 billion, and the value of the additional sorghum stover produced will be about US$ 740 million.

By 2020, DRYLAND CEREALS will generate at least 150 new widely adapted varieties that have the traits preferred by farmers and consumers in target regions and countries. The formal and informal seed sectors (public and private) will be mobilized to produce and disseminate quality seed of improved varieties, with particular attention paid to farmers who usually face the greatest difficulties in accessing seed and other inputs. Training courses and workshops will strengthen the technical capacity of researchers and development specialists involved in the initiative. The research capacity of NARES will be strengthened with the training of 60 PhD and MSc students. Moreover, DRYLAND CEREALS will implement a gender-focused approach to R4D in the drylands, with particular emphasis given to food processing and value-adding business opportunities for women.

To achieve its vision, DRYLAND CEREALS is structured in terms of six interrelated Strategic Objectives:

- **SO 1** – **Better targeting of opportunities for technology development and delivery** of dryland cereals to smallholder farmers in Africa and Asia
- **SO 2 – Enhancing the availability and use of genetic diversity, genomics and informatics** to enhance the efficiency of dryland cereal improvement
- **SO 3** – **Developing improved dryland cereal varieties and hybrids** for increased yield, quality and adaptation in smallholder farmers' fields
- **SO 4** – **Developing sustainable crop, pest and disease management options** to capture genetic gains from improved dryland cereal varieties and hybrids
- **SO 5 – Enhancing effective seed and information systems** for better delivery of improved technology packages to smallholder farmers
- **SO 6** – **Adding post-harvest value and improving market access** of dryland cereals to provide smallholder farmers more benefits from dryland cereals

We will link with a number of other CRPs, including CRP 1.1 (Integrated agricultural production systems for the poor and vulnerable in dry areas); CRP 2 (Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor); CRP 3.5 (Grain legumes); CRP 3.7 (Sustainable staple food productivity increase for global food security: livestock and fish); CRP 4 (Agriculture for improved health and nutrition); CRP 5 (Durable solutions for water scarcity and land

and ecosystem degradation); and, CRP 7 (Climate change, agriculture and food security), as well as other major donor-funded initiatives. The program will build on existing knowledge, previous achievements, and the considerable strengths of a wide range of partners to focus attention on opportunities in the drylands to improve the livelihoods of smallholder farmers and their families through improved food security, increased incomes, and better household nutrition.

PROGRAM JUSTIFICATION

DRYLAND CEREALS FOCUS CROPS

The drylands of Africa and South Asia are among the most marginal crop production environments. The people who farm there have few options in terms of crops, and commonly depend on the hardiness of barley, finger millet, pearl millet and sorghum – four robust crops that require less moisture and nutrients to survive, and that respond well to additional moisture and nutrients when available. It is also interesting to note that the demand for dryland cereals – often referred to as coarse grains – is on the rise in India. Below are brief descriptions of these crops; much more detail can be found in Appendix 1.

Barley (*Hordeum vulgare* L.) is grown on 18 million hectares in developing countries, often at the fringes of deserts and steppes or at high elevations. The crop has many uses. Its grain is used as feed for animals, for malting, and as food for direct human consumption. In the highlands of Tibet, Nepal, Ethiopia, Eritrea, in the Andean countries, and in North Africa, barley is used as human food either for bread making (usually mixed with bread wheat) or in traditional recipes. In recent years the use of barley as food has gained momentum, especially in North America and Europe, gaining the label as a 'functional' food. Still, about 75% of all barley is used for animal feed; 20% for malting; and the remaining 5% for direct food use. Barley straw is used as animal feed in many developing countries, and for animal bedding and as cover material for hut roofs. After the harvest, barley stubble is grazed during the summer in large areas of West Asia and North Africa. Barley is also used for green grazing or is cut before maturity and either directly fed to animals or used for silage. Malting barley is grown as a cash crop in a number of developing countries. Utilization for malting and by the brewing industry has picked up recently with an increase of consumption of beer and other malt products. In a 2009 ranking of cereal crops in the world, barley was fourth both in terms of quantity produced (136 million tons) and in area cultivated (56.6 million ha).

Finger Millet [*Eleusine coracana* (L.) Gaertn] plays an important role in both the dietary needs and incomes of many rural households in eastern and southern Africa and South Asia, accounting for 10% of the 38-50 million hectares sown to all the types of millet globally. Finger millet is rich in fiber, iron and calcium. It is the most important small millet in the tropics (where 12% of the global millet area is found) and is cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from the Near East to the Far East), predominantly as a staple food grain. Major producers of finger millet include Uganda, India, Nepal and China. The crop has high yield potential (more than 10 t/ha under optimum irrigated conditions) and its grain stores very well. Even so, like most millets it is grown mainly as a rainfed crop in marginal environments having low soil fertility and limited moisture. Finger millet is originally native to the Ethiopian highlands and was introduced into India approximately 4000 years ago. It is well adapted to higher elevations and is grown in the Himalayan foothills and the East Africa highlands, up to 2300 masl.

Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] is the world's hardiest warm season cereal crop. It can survive even on the poorest soils in the driest regions, on highly saline soils and in the hottest climates. It is annually grown on nearly 30 million hectares across the arid and semiarid tropical and subtropical regions of Asia, Africa and Latin America. Pearl millet is a staple food for more than 90 million people who live in the drier areas of Africa and Asia. India is the largest single producer of pearl millet, both in terms of area (9.3 million hectares) and production (8.3 million tons). The West and Central Africa (WCA) region has the largest area under millets in Africa (15.7 million hectares), of which more than 90% is pearl millet. Since 1982, the millet area in WCA has increased by over 90%, and productivity has risen by 12% (up from 800 to 900 kg/ha). Production has increased by about 130% (up from 6.1 to 14.1 million tons), most of which has come from increases in cultivated area. Lack of seed production in the region, however, is a major bottleneck in the spread of improved cultivars. The same is true in eastern and southern Africa (ESA), where pearl millet is cultivated on about 2 million hectares.

Sorghum [*Sorghum bicolor* (L.) Moench] is cultivated in the drier areas of Africa, Asia, the Americas and Australia. It is the fifth most important cereal crop, and is the dietary staple of more than 500 million people in more than 30 countries. It is grown on 42 million hectares in 98 countries of Africa, Asia, Oceania and the Americas. Sorghum is a staple in sub-Saharan Africa, its primary center of genetic diversity. It is most extensively cultivated in zones of 600-1000 mm rainfall, and where poor soil fertility, soil acidity and aluminum toxicity are common. The crop is extremely hardy and produces even under very poor soil fertility conditions. It is adapted to a wide range of temperatures, and is thus found even at high elevations in East Africa, overlapping with barley. Sorghum has good resistance to grain mold and thus has a lower risk of contamination by mycotoxins. The grain is mostly used for food purposes, and is consumed in the form of flat breads and porridges (thick or thin, with or without fermentation). In addition to food and feed it is used for a wide range of industrial purposes, including starch for fermentation and bio-energy. Sorghum stover is a significant source of dry season fodder for livestock. It also serves as construction material and is used as fuel for cooking. Sweet sorghum is emerging as a multi-purpose crop. It can provide food, feed, fodder and fuel (ethanol), without significant trade-offs among any of these uses in a production cycle.

RISING DEMAND FOR DRYLAND CEREALS

The aggregate demand for barley, millets (mainly pearl millet) and sorghum is projected to rise in all our target regions and countries. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which was developed by IFPRI, shows significant increases in demand for dryland cereals by 2020 over the model's year 2000 baseline (Table 1 and Appendix 3). Demand for barley will increase by about 64 million tons (44%) over the 20-year period, while demand for millets will grow by more than 8 million tons (39%) and sorghum by over 11 million tons (48%).

Demand is projected to rise largely because of population growth in dryland areas, coupled with: 1) an increasing need for feed and fodder/straw to support livestock in mixed crop-livestock systems; 2) new market opportunities; and 3) the simple fact that there are few if any alternative crops that will grow in harsh dryland environments. While it is true that per capita demand for dryland cereals will fall relatively faster than for other cereals as incomes rise, total demand will continue to increase for the reasons mentioned above. See Appendix 3 for a full discussion of demand trends and drivers.

Table 1. Demand projection for dryland cereals in 2020 ('000 MT) from IMPACT model

Region	Sorghum		Millet		Barley	
	2000	2000	2020	2020	2000	2020
WCA	9,435	9,772	16,009	15,580	-	-
ESA	6,633	2,028	3,431	10,732	4,378	7,180
CWANA	-	-	-	-	38,072	53,942
SA	7,706	9,680	10,360	8,798*	66,421	95,502
Total	**23,774**	**21,480**	**29,800**	**35,110**	**108,873**	**156,624**

* Food demand only, excluding demand for feed

WHY WORK ON THESE CROPS UNDER A SINGLE CRP?

The demand for these crops is driven by a common set of factors. For example, about 50% of the demand for them is related to sustaining livestock (feed and fodder/straw) in integrated crop-livestock systems, while 40% of what is produced is consumed directly by the poor as food in various forms. Moreover, a growing portion of dryland crops is being marketed for various industrial uses (e.g. malting, sweet syrups, and ethanol), which is providing increasing amounts of cash income to smallholder farmers.

In addition to these shared demand drivers, a number of other characteristics make it more efficient and effective to focus R4D initiatives on them under a single CRP. All four crops, for example, lend themselves to similar breeding and development approaches, such as the use of genomic-based methods, the exploitation of heterosis and participatory development.

Given their substantial economic value (Table 2) and their importance as a mainstay for the hundreds of millions of people living in our target areas, relatively limited resources have been allocated to dryland cereals. Working on them together enables us to create a much-needed minimum critical mass in research aimed at achieving research outcomes and development impacts.

There are a number of common researchable issues associated with these crops, including, but not limited to:

- Understanding the nature of tolerance these crops share towards drought, high temperatures and low soil fertility to provide solutions for future stresses due to climate change;
- Determining the potential for optimizing the combined production and quality of grain and stover to meet future livestock demands;
- Development of alternative weed management strategies given the limited availability of labor in sparsely populated dryland areas;
- Addressing similar constraints faced by these crops regarding seed delivery systems, market access, production and market-related policies; and
- The importance of improving post-harvest handling and processing for better shelf life and nutritional value.

Table 2. Production (in million tons) and value of production (VOP in US$ billions) for dryland cereals (barley, millets, sorghum) worldwide and in low-income food deficit countries (LIFDC[1])

	Production (MT)		VOP (US$ billion)	
Crop	**LIFDC**	**World**	**LIFDC**	**World**
Barley	10.1	155.1	2.94	36.76
Millets (finger and pearl)	33.5	35.2	13.37	13.68
Sorghum	36.7	66.8	10.98	15.60
Total Dryland Cereals	**80.3**	**257.1**	**27.29**	**66.04**

[1] FAO's classification and criteria for low-income food-deficit countries (LIFDC) can be found at http://www.fao.org/countryprofiles/lifdc.asp?lang=en

All four crops are used in multiple ways – directly for food, as critically important sources of feed and fodder, and increasingly for industrial purposes. Moreover, women play a prominent role in the cultivation, processing and preparation of dryland cereals, which opens opportunities to significantly and directly improve their well-being.

As noted earlier, barley, finger millet, pearl millet and sorghum all possess genetic yield stability and high levels of water and nutrient use efficiency, traits that indicate considerable potential for reducing production risks for resource-poor dryland smallholders, especially under future climate change. They also have a strong genetic tolerance for drought, high temperatures and soil salinity, as well as high levels of resistance to pests and diseases. Thus, joint research on crop physiology and root characteristics will hasten the identification of causal factors for increased stress tolerance, leading to the efficient development of more tolerant varieties.

There is significant potential for capacity building that is relevant to all four crops, and there are a number of organizations striving to address the need for using improved seed and production practices, and to improve the capacity and knowledge of farmers, post-harvest processors, traders, research and development specialists, and policymakers. While not currently well linked, all these organizations work in various ways to promote sustainable improvements in the livelihoods of smallholders in dryland areas, strengthen dryland crop-livestock systems, and protect fragile soil and water resources. DRYLAND CEREALS will provide a mechanism through which the agendas and activities of these different organizations can be better coordinated.

Finally, the R4D efforts and outputs produced by DRYLAND CEREALS will be demand driven, and as described earlier will feature linkages to the work being done in other CRPs – especially, CRP 1.1 (Dryland Systems) and 3.7 (Livestock), but also to CRP 2 (Policies, Institutions and Markets), CRP 3.5 (Grain Legumes), CRP 4 (Nutrition and Health), CRP 5 (Land and Water) and CRP 7 (Climate Change). These linkages will be more effective and efficient for those CRPs if they are dealing with a single Project focused on dryland cereals.

TARGET REGIONS AND FARMING SYSTEMS

DRYLAND CEREALS will be working in four major target regions – West and Central Africa (WCA), Eastern and Southern Africa (ESA), Central and West Asia and North Africa (CWANA), and South Asia (SA). Within those regions, we will be targeting the prevailing farming systems that feature our four focus crops (Appendix 2).

We began the process of delineating the geographical focus of DRYLAND CEREALS by first identifying the primary farming systems in developing countries in which barley, finger millet, pearl millet and sorghum are currently grown. With few exceptions, we established a minimum threshold of 1.0 million hectares in a farming system to merit the allocation of research resources from the Program. With this primary filter in place, we then factored in several other important considerations, including rural and urban populations, the number of poor (earning less than US$ 1.25/day), the number and prevalence of stunted children (as an indicator of malnutrition), and the probability of drought (Table 3).

Table 3. Population, poverty and malnutrition indicators, by region

Indicator	WCA	ESA	CWANA	SA	Total
Rural Population (millions)	154	254	164	947	**1,510**
Urban Population (millions)	72	86	267	376	**801**
Stunted Children (millions)	13	22	10	80	**125**
Prevalence of Stunting (%)	32	38	34	37	**35**
Number of poor (millions earning less than US$ 1.25/day)	142	157	28	589	**916**
Probability of Drought (%)	19	38	11	22	**23**

In addition, we also considered the geographical priorities expressed in the Strategy and Results Framework (SRF), which encourages a strong focus on Africa and Asia. The end result of this initial targeting and priority setting effort indicates that DRYLAND CEREALS research resources should be focused on (Table 4):

- Nearly 9.6 million hectares of barley in seven different farming systems in three regions (Eastern and Southern Africa, Central and West Asia and North Africa, and South Asia);
- Just under 1.0 million hectares of finger millet in two different farming systems found in Eastern and Southern Africa;
- About 21.6 million hectares of pearl millet in six farming systems spread across two regions (West and Central Africa and South Asia); and
- More than 18.6 million hectares of sorghum in eight major farming systems found in three regions (West and Central Africa, Eastern and Southern Africa, and South Asia).

WHERE WE ARE *NOT* WORKING, AND WHY

As can be seen in Table 4, DRYLAND CEREALS will not be working everywhere its crops are grown. Instead, resources will be focused on key farming systems in two large regions in Africa (WCA and ESA), Central and West Asia and North Africa (CWANA), and South Asia. This is primarily based on four considerations: 1) size of the area sown to dryland cereals, 2) a principal focus on drier environments, 3) the availability of alternative suppliers, and 4) the synergies being achieved with current, long-standing partners. For example:

- In South Asia, we will not devote resources to research on finger millet or rainy season sorghum; ICAR is handling those as part of its own ongoing research and development program. ICRISAT is focused on harsher environments in South Asia, where yields are low and there are large numbers of smallholders. Thus, CRP resources will be allocated to research that will benefit the large post-rainy season sorghum area. However, because of the effective ICAR/ICRISAT collaboration on pearl millet – all of which is grown during the rainy season – that will continue in the region using CRP resources. And while the area of barley in the region is now relatively small, demand is increasing for barley as forage and as a cash crop (for malting). In addition, because of its drought tolerance, barley can perform reasonably well on residual moisture and its earliness makes it a good fit for the current rotations being used.
- In Eastern and Southern Africa, the primary use of CRP resources will be for work targeting the 5.2 million hectares of sorghum in the region. Resources will also be devoted to the nearly 1 million hectares of finger millet and some 1.2 million hectares of highland barley.
- The large areas of pearl millet and sorghum will receive considerable attention in West and Central Africa, though nearly 2 million hectares of sorghum grown in the vast pastoral areas of the region will not because the sorghum grown in those areas is so spread out and remote as to greatly reduce the Program's ability to address them.
- Barley will be the focus in CWANA, and most of the research resources flowing to that region will be used in selected countries in the Middle East and North Africa; this work will create spillovers for regions that are not of primary focus such as Latin America and China; there is no finger millet grown in the region and only small amounts of pearl millet and sorghum.

Table 4. Regions and primary farming systems in the developing world where dryland cereals are grown; targeted regions and farming systems are shaded in grey.

Region/Farming system	Barley Area (ha)	Finger Millet Area (ha)	Pearl Millet Area (ha)	Sorghum Area (ha)
West and Central Africa (WCA)				
Cereal root crop mixed			3,841,000	5,335,000
Agro-pastoral			6,938,000	3,706,000
Pastoral			3,452,000	1,948,000
Total WCA			**14,231,000**	**10,989,000**
Eastern and Southern Africa (ESA)				
Maize mixed	124,000	740,000		1,294,000
Cereal root crop mixed	5,000		436,000	1,001,000
Agro-pastoral	12,000	50,000	501,000	1,035,000
Pastoral	103,000		855,000	2,068,000
Highland temperate mixed	1,185,967	242,000		473,000
Total area ESA	**1,429,967**	**1,032,000**	**1,792,000**	**5,871,000**
Central and West Asia and North Africa (CWANA)				
Dryland mixed	2,299,849		5,631	3,855
Highland mixed	1,171,254		58,161	167,588
Rainfed mixed	1,294,046		3,599	18,806
Pastoral	1,291,569		38,344	1,746
Small scale cereal-livestock	1,693,334		16,424	
Total CWANA	**7,750,052**		**170,775**	**191,995**
South Asia (SA)				
Rice-wheat	674,208 (post-rainy season)	16,650 (rainy season)	2,870,047 (rainy season)	577,749 (rainy season) 2,638 (post-rainy season)
Rainfed mixed	96,100 (post-rainy season)	1,122,053 (rainy season)	3,399,448 (rainy season)	2,547,283 (rainy season) 1,690,011 (post-rainy season)
Dry rainfed		42,515 (rainy season)	1,090,868 (rainy season)	320,522 (rainy season) 2,497,217 (post-rainy season)
Total area SA	**770,308**	**1,181,218**	**7,360,363**	**7,635,420**
Total of all Farming Systems	**9,950,327**	**2,213,218**	**23,505,523**	**24,687,415**
Total of Targeted Farming Systems	**9,610,227**	**928,000**	**21,591,364**	**18,626,228**
% Targeted Farming Systems of Total	**97%**	**44%**	**92%**	**75%**

WHAT LESSONS HAVE WE LEARNED?

A number of relevant lessons pertaining to the importance and practice of dryland cereals research have emerged during the preparation of this proposal. These lessons, along with the perceived challenges and opportunities for the Program described below, have helped shape our Strategic Objectives.

- Dryland cereals hold considerable promise for stable yields in the face of climate change and the likelihood of more erratic rainfall patterns and higher temperatures in important production zones and cropping systems, including those where less resilient crops are currently grown. Even so, while these crops are more reliable than alternatives in such harsh environments, dryland cereals are already being pushed into areas where they cannot perform well;
- Adoption of improved dryland cereal technologies has been limited over the years by poor farmer access to seed and relevant information;
- Seed and other inputs should be packaged in smaller, more affordable sizes to encourage purchase by smallholders;
- Dryland cereal farmers' decisions about adopting improved varieties must take into account multiple uses, consumer preferences, and the international and local markets for the crops, a dynamic that is not yet well understood by researchers;
- Hybrids are proving viable in certain regions and countries, and there is significant private sector interest in developing that market (mainly in India);
- The ongoing livestock revolution has important implications for dryland cereal demand, and for how research should be focused (for example, because we now know that grain/stove tradeoffs are minimal, we can give more research attention to improving the quantity and quality of stover without sacrificing grain yield or quality);
- There is a renewed and growing interest in India in coarse grains and traditional recipes using them, especially in urban areas; and
- Genomic technologies and tools have advanced rapidly in recent years and are applicable to dryland cereal crops. In combination with better access to timely, accurate data and information, the breeding of improved varieties can be greatly accelerated.

THE CHALLENGES AND OPPORTUNITIES FOR DRYLAND CEREALS

Beyond capitalizing on these commonalities among dryland cereals, stakeholders in DRYLAND CEREALS have identified a number of other important challenges and opportunities that should be addressed. These further strengthen the rationale for a collective focus on major dryland cereals under a single CRP.

Sources of genes for stress tolerance and adapting to climate change

One of the principal wildcards facing global agriculture is the probable impact of global warming. Recent studies suggest that the production of major commodities has declined since 1980 due to global warming (Lobell et al., 2011). Furthermore, it is estimated that given current warming trends in sub-Saharan Africa, by mid-century there could be declines as large as 20% in the production of major cereals even including millet and sorghum (Schlenker and Lobell, 2010). The poor who depend on agriculture for their livelihoods and are less able to adapt will be disproportionately affected (World Bank, 2007). Climate-related crop failures, fishery collapses and livestock deaths already cause significant economic losses and undermine food security, and these are likely to become more severe as global warming continues. A recent study estimates the annual costs of adapting to climate change in the agricultural sector to be over US$ 7 billion (Nelson et al., 2009).

As environments that are currently considered favorable for agriculture become hotter and dryer over time, dryland cereals will become increasingly suited for production in areas where other crops are now grown. DRYLAND CEREALS research planned under Strategic Objectives 2 and 3 will contribute to meeting the eventual needs of smallholders in these areas. The use of dryland cereals as cost-effective alternatives should be accelerated through increased investments and wider, more diverse partnerships to facilitate adaptation to changing agro-ecological conditions. A close partnership with CRP 7 (Climate Change) will ensure that DRYLAND CEREALS effectively targets improved technologies to the conditions of new dryland environments and provides scientific data to enhance climate change models for dryland crops.

The looming threat of higher temperatures and more vicious droughts due to climate change is a major concern. Fortunately, barley, millets and sorghum possess the most exceptional genetic traits for climate-related stress resistance that evolution has been able to engineer (i.e., tolerance to such major abiotic stresses as drought, water logging, heat, salinity and acid soils). At the same time, the CGIAR has unparalleled positioning on the genetics of these crops, with its extensive germplasm collections and leading global plant breeding expertise focused on the needs of the developing world. An enormous opportunity thus exists for the CGIAR and an expanded group of partners to conduct strategic research and better tap the stress tolerances found in these crops.

Since the CGIAR's work spans all the major staple cereals, the CG and its partners are ideally placed to generate and foster such knowledge spillovers. In addition to the scientific gains, this could be a mechanism for building stronger synergies and collaboration between the crop-focused CGIAR Centers. The Generation Challenge Program (GCP), an important partner in this CRP, was established specifically for this purpose and has demonstrated significant progress towards the characterization and use of genetic diversity.

Responding to the "Livestock Revolution"

Mixed crop-livestock smallholder farming enterprises are commonly found in dryland zones, and the nutritious crop residues produced by dryland cereals (especially sorghum, but also barley straw) are a vital source of fodder for livestock. To date, however, little research has been done to increase the quantity and nutritive quality of dryland crop residues. The traditional focus of research has been on increasing the output of grain, and the value of the "leavings" was of secondary interest.

Smallholder farmers, on the other hand, have a strong interest in their crop residues. In fact, the widespread availability of crop residues and the extent of their use as livestock fodder mark them as a strategic feed resource of the highest order. Furthermore, it is very important to realize that such residues require no specific allocation of water and land; they result simply from growing crops whose primary product is grain. Thus, any improvement in the nutritive value of crop residues, however small, can have considerable value and impact.

There appears to be significant genetic variability for grain yield, stover and straw yield, and fodder quality among the dryland cereals, and there are limited negative correlations among these attributes. These variations came about largely by chance, and existing genetic variability can easily be exploited through targeted breeding to increase the productivity of mixed crop-livestock systems. The work that will be done under Strategic Objectives 1, 2 and 3 will give considerable attention to better understanding the dynamics of the livestock revolution as a demand driver for dryland cereals, and to research designed to improve the quantity and quality of fodder (and feed) in our target environments while maintaining or improving grain yields.

Sustainable increases in productivity and improvements in nutrition

Dryland cereals are among the hardiest of crops, enabling their persistent survival in harsh environments. They all have notable resistance/tolerance to a range of abiotic and biotic stresses commonly encountered in the dryland ecosystems in which they are grown. This contributes to their production stability and the high potential that exists for achieving further sustainable increases in yields, productivity and profitability.

Improving productivity – Further improvement in the genetic potential of barley, millets and sorghum, mainly through Strategic Objective 3, is essential for increasing grain yield and quality, as well as for improving the quantity and quality of their stover and straw. Strategic Objective 4 will use the products generated by Strategic Objective 3 as it strives to identify improved agronomic practices that will minimize yield gaps, reduce labor requirements (drudgery), and improve field-level production and product quality. We must continue to probe the dryland cereals gene pools to identify additional sources of tolerance and resistance, gain knowledge about how these genes contribute to crop stability, and ensure that all varieties released contain appropriate levels of resistance. This will be an important aspect of work done under Strategic Objective 2 that will feed into SO 3, and this need, along with other researchable issues common to these crops, reinforces the idea of working on them as a group – capitalizing on both the minimum critical mass afforded by DRYLAND CEREALS, as well as the efficiencies of the partnerships envisioned.

Improving nutritional content – Increasing affluence is contributing to a rising demand in urban markets for value-added products, especially those with more nutritive value. Finger millet has high levels of iron and fiber and exceptionally high levels of calcium. It also has better energy content, making it ideal for weaning children, pregnant and nursing mothers (Shashi et al., 2007). Moreover, it is being used as a therapeutic food in programs for diabetics and people who cannot tolerate gluten.

Consumers – especially those in urban areas – are rediscovering the health benefits that come with eating traditional foods and newer processed food products prepared using various dryland cereals. Barley, millets and sorghum have high levels of important micronutrients, such as iron and zinc. Barley beta-glucans lower blood cholesterol, and low glycaemic indexes of barley, millet and sorghum make these cereals suitable for diets of Type II diabetics. Barley is also a rich source of tocols, which are known to reduce serum LDL cholesterol through their antioxidant action.

During the last decade there has been increasing interest in incorporating barley in the human diet to improve health, mainly in developed countries and in major urban areas of developing countries. This is boosting the development of food products from barley and consumer interest in eating them. The effectiveness of barley beta-glucans in lowering blood cholesterol and its low glycaemic index in diets for Type II diabetics is widely accepted. The consumption of barley reduces the rate at which glucose is released to the blood (Björck et al., 2000) causing a reduction in the Glycaemic Index (GI). Beta-glucans derived from barley help reduce its glycaemic response (Cavallero et al., 2002). In addition, barley is a rich source of tocols, which are known to reduce serum LDL cholesterol through their antioxidant action. Food products made from hulless barley are considered whole-grain foods, and in North and East Africa, producing and marketing such processed foods is becoming a common source of income for women.

Pearl millet and sorghum have inherently higher content of important micronutrients, such as iron and zinc. In addition ICRISAT and its partners have recently identified varieties with significantly higher micronutrient content, which can help consumers avoid micronutrient deficiencies. These two cereals are also reasonably good sources of protein and fat – and thus fat-soluble vitamins. Pearl millet and sorghum are gluten-free, and like barley have low glycaemic indices.

DRYLAND CEREALS Strategic Objectives 2, 3 and 4 will pay particular attention to at least maintaining – and where possible, increasing – the micronutrient content of dryland cereal grain. They will also work to improve the nutritional value of stover and straw for use in smallholder mixed crop-livestock systems. Consumers are learning more about the advantages of consuming these traditional “coarse grain” cereals (see Box), and research on post-harvest, value adding processing (as part of Strategic Objective 6) is required to help ensure that some of the preferred, traditional dishes can be made more readily available in urban markets.

Improving the delivery, availability and adoption of dryland cereals
A persistent challenge for dryland cereals is the lack of effective seed production and delivery systems in many of our target areas, which limits the availability of improved varieties and related technologies and information for smallholders. Research will be done under Strategic Objective 5 to more clearly identify the constraints to establishing viable delivery systems and opportunities for overcoming them. The lack of such systems also contributes to the poor adoption track record for improved dryland cereal technologies. Another major factor limiting adoption is that our target farmers in general are among the poorest of the poor and are farming marginal lands in harsh and unpredictable environments. They can ill afford to take risks with new technologies. Thus, Strategic Objective 6 will conduct research aimed at more fully understanding technology adoption dynamics under such risky circumstances, and will also explore options for increasing household incomes through value-adding activities and better market access.

Scarcity of alternative suppliers
Although the importance of dryland cereal crops is increasingly recognized, only a few organizations other than the CGIAR are investing in them. These are primarily public-sector institutions, such as INTSORMIL, and several universities in the USA, EU, UK and Australia. The private sector understandably gives more priority to other crops with large cash markets, although a few do have breeding programs focused on one or more dryland cereal. National governments in developing countries do support work on barley, millets and sorghum, but usually on a relatively small scale. Notable exceptions include EMBRAPA in Brazil and ICAR in India, who both have significant research programs given the importance of these cereals in these countries. Unfortunately, many of the government institutions where dryland cereals are important crops are woefully under-financed, especially in the poorest (and driest) countries.

Addressing this investment gap is directly in line with the CGIAR’s core mission. The CG System was originally founded with a focus on helping the very poorest and hungriest in the developing world. The CGIAR must continue with and strengthen its flagship focus on the forgotten poor – those outside the mainstream of economic and political influence. It must help them find ways to grow their way out of poverty, and become more important actors in national economies (and in doing so, mattering more to decision-makers).

There is strong evidence that the CG can play an effective role in catalyzing the interest of the private sector in dryland crops. The vigorous millet and sorghum private seed industry in India, for example, openly credits the Indian Council of Agricultural Research (ICAR), with the help of ICRISAT, as being responsible for their success. These companies say they would not have been able to start profitable businesses without prior research having created improved germplasm, particularly hybrids. In fact, they are now funding a significant portion of ICRISAT’s hybrid parents improvement research in India, through annual consortium membership fees. Such partnerships have transformed the way plant breeding is done by a number of CG centers operating in Asia, Africa and Latin America, and yet they present but a glimpse of what may be achievable through creative arrangements with a more diversified array of R4D partners in the future.

DRYLAND CEREALS IMPACT PATHWAY

DRYLAND CEREALS will gauge its impacts in the context of the CGIAR Consortium Strategy and Results Framework. The SRF identifies three key stages in the outreach process: the development and delivery of outputs, the co-production of outcomes with those who will directly use them, and engagement with those who deliver impacts to our ultimate beneficiaries – the smallholder farmers of Africa and Asia.

The DRYLAND CEREALS impact pathway has its focus on the millions of smallholder farmers whose lives and livelihoods we are working to improve. Priorities for research interventions are aided by knowledge gained from targeted dryland cereal value chain and adoption studies (Strategic Objective 1). Five additional Strategic Objectives work in concert to yield outputs that are the substrates for various research outcomes. These research outcomes feed into development outcomes that, in turn, contribute to impacts such as improved food security, greater resilience, increased income, improved gender equity, and a reduced environmental footprint (Figure 1). For example, increased access to and enhanced use of genetic resources and tools (from Strategic Objective 2) contribute to more efficient breeding programs and improved varieties, especially those that can perform under harsh environments. Higher yielding, more robust and more nutritious varieties (Strategic Objective 3) will give greater benefits where pests and diseases are better managed and natural resources are optimally used (Strategic Objective 4). Farmers will have better access to improved technology packages when disseminated through affordable and effective seed, input and communication systems (Strategic Objective 5). Improved access to markets and increased attention to and by end-users (Strategic Objective 6) should drive change and create new demand for varieties and other technologies in a feedback loop. Finally, improved capacity of partners for research and innovation should increase the probability that outputs lead to the relevant outcomes.

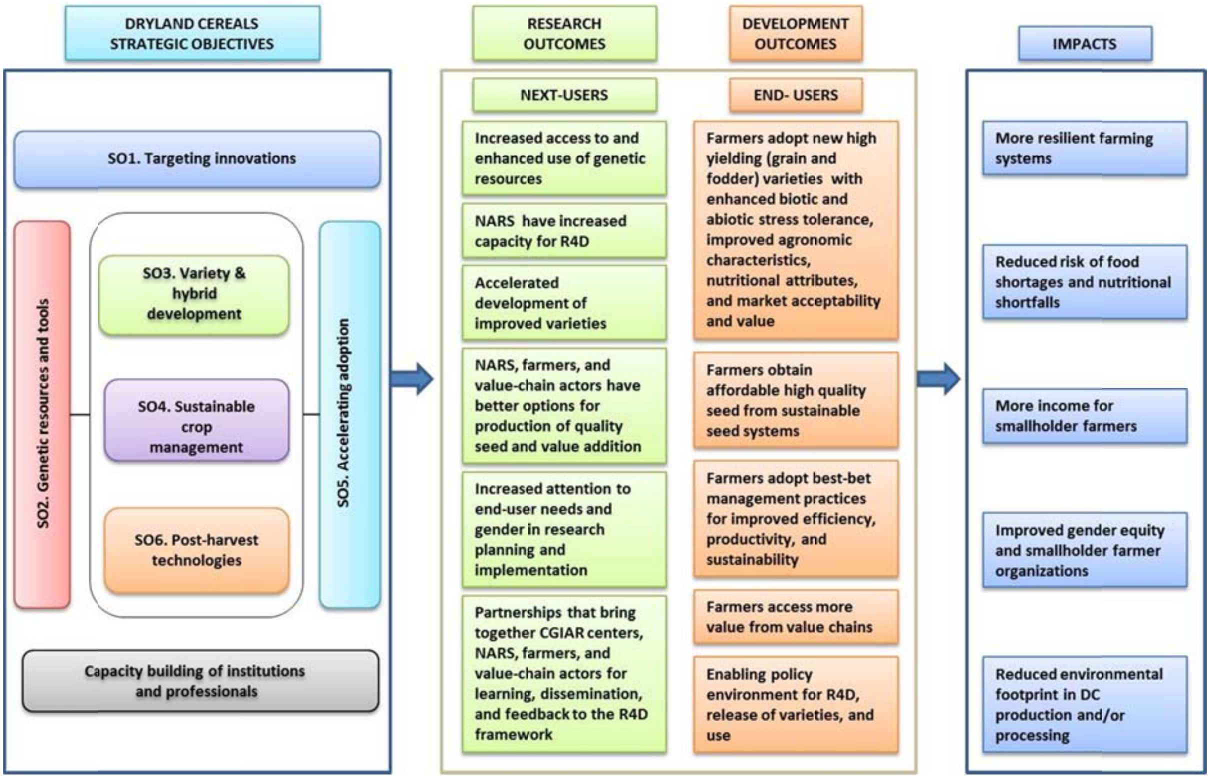

Figure 1. Strategic Objectives, research and development outcomes and impacts

The pathway depicted in Figure 2 shows in greater detail where the key actors are adding or absorbing value. The actors include R4D partners (NARES, ARIs, IARCs and private sector entities), development and delivery partners (which includes a range of NGOs, CSOs and private sector organizations), smallholder farmers, small- to medium-sized agro-enterprises and larger-scale agro-industries, through to rural and urban consumers. Our development partners are the primary "delivery mechanism" for moving better seed and other inputs, better agronomic practices, and better information and other innovations into the hands of smallholder farmers, which will then allow them to improve their farming operations and related processing and marketing activities. For many farmers – those mired in a subsistence existence – this alone will be a big step towards finally being able to meet their own household food needs.

In order to have maximum impact, however, we must do more. We need to help create an environment in which smallholder farmers can produce marketable surpluses and in which they can gain access to more efficient and effective markets, access that will transform surpluses into additional income and open opportunities for establishing commercially viable SMEs and/or link directly with agro-industries. Beyond that, we must work through development organizations, educational institutions and governments to further educate consumers about the nutritional value of these crops, an "awareness trend" that is already picking up speed in South Asia and holds similar promise in Africa, especially in urban areas. As consumers increasingly partake of coarse grains, whether in the form of traditional foods or as new, timesaving processed food products, the demand for additional surplus production will continue to increase.

While this pathway may appear overly simplified and rather linear, we recognize that it is anything but. Feedback loops and multiple roles abound in the real world. Smallholder farmers, for example, are of course the producers of dryland cereals, but are also critical sources of knowledge about the crops who are often involved in participatory on-farm research; they may be involved both in household and (increasingly) in commercial food processing; and they are certainly consumers as well.

A very large number of producers and consumers can potentially be reached through DRYLAND CEREALS. We made an initial estimate (Appendix 3) that there are at least 33 million beneficiaries to be potentially reached (Table 5). We also used *ex-ante* analysis (Appendix 3) to provide a preliminary estimate of potential economic benefits from DRYLAND CEREALS. Because of adoption lags, a 10-year timeframe was used to project an additional net income from dryland cereal grain of about US$ 1.5 billion and an additional US$ 740 million from stover. Because the technologies that will be developed are mainly targeting production, processing, and marketing constraints, most of these benefits will accrue to poor farmers and their family members. As these crops are mostly for domestic consumption, the benefits are shared between consumers, producers, and traders, with a larger portion of the benefits accruing to consumers.

Not surprisingly, gender plays a very important role in all this. About 70% of the smallholder farmers we want to reach are women and we obviously need to understand upfront the constraints they face and their preferences so that outputs can be tailored to gender-based demands. We also need to know how to create market opportunities that can benefit women, opportunities that lead to empowerment and improved livelihoods. Outputs relating to nutrition and food security are particularly relevant to women, as are those relating to improving feed and fodder quantity and quality since women often care for household livestock. Improved processing technologies that make it easier for women to process food for home consumption, and to process it in larger quantities for storage, can help reduce drudgery and the workload handled by women.

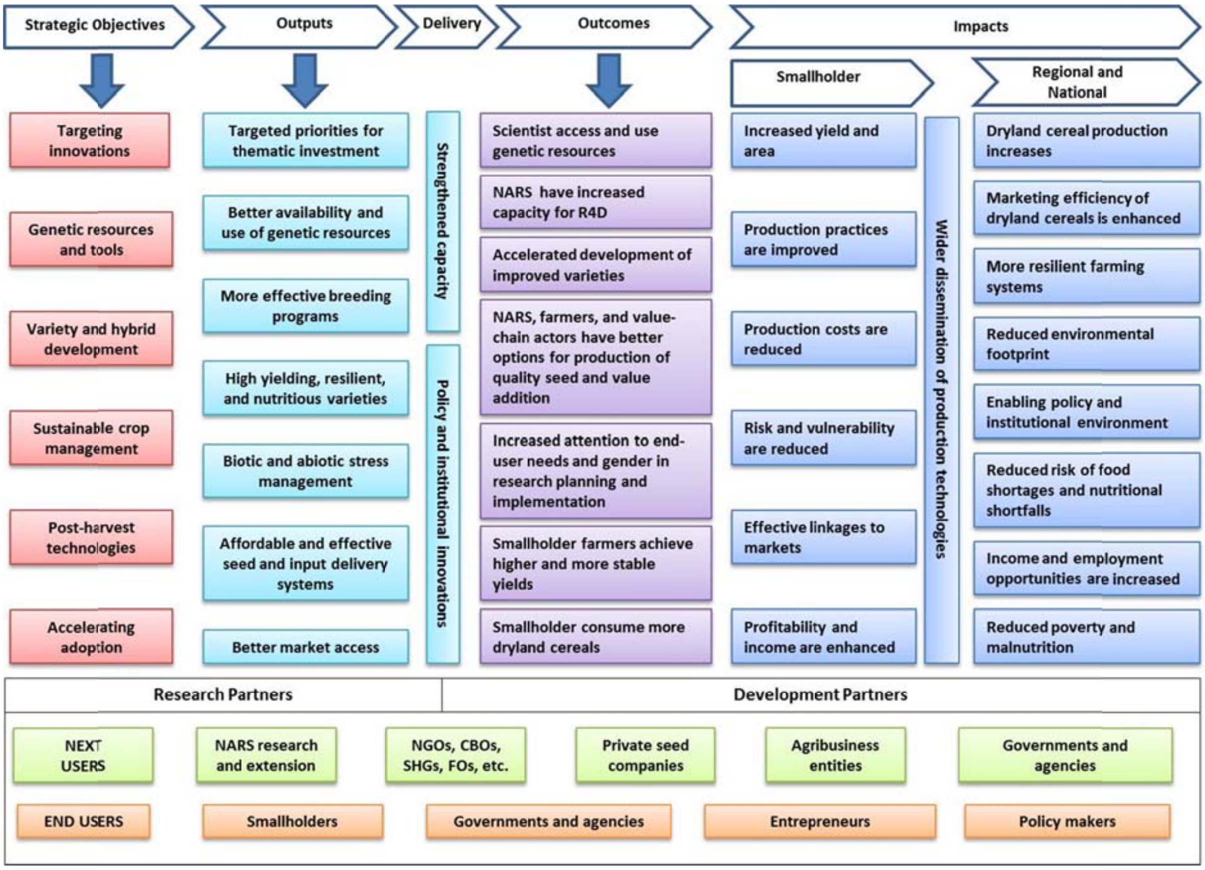

Figure 2. The DRYLAND CEREALS impact pathway

DRYLAND CEREALS partners must consider the whole value chain to make sure different outcomes have the desired behavioral impacts on different actors. As noted earlier in this section, we realize that participants along the value chain interact in a number of ways and that there is a multiplicity of feedback loops not shown here. The role of governments in creating enabling environments is also critical, as are gender considerations and capacity strengthening.

Table 5. Estimated number of potential beneficiaries by crop and region (millions)

Crop	Region				Total
	WCA	ESA	CWANA	SA	
Barley	–	0.94	5.93	0.64	7.51
Millet	3.05	1.98	–	2.90	7.93
Sorghum	2.40	7.37	–	8.03	17.80
Total	**5.45**	**10.29**	**5.93**	**11.57**	**33.24**

DRYLAND CEREALS STRATEGIC OBJECTIVES

DRYLAND CEREALS is focused primarily on the core competencies of crop improvement (including the use of genetic resources and genomics), cropping systems (use of sustainable crop, pest and disease management options) and post-harvest technologies (appropriate storage, processing and marketing), with significant collaborative efforts with other CRPs in production systems and price, trade and policy areas (Figure 3). Beyond these traditional core competencies, DRYLAND CEREALS also brings expertise and focus to new areas identified in the Strategy and Results Framework (SRF), such as climate change adaptation/mitigation (tapping dryland cereals for traits and genes for drought, heat and nutrient use) and nutrition and health.

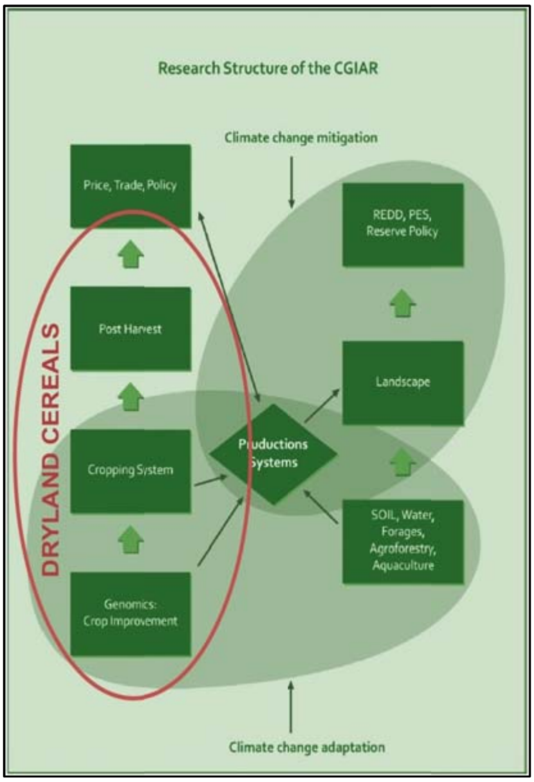

Figure 3. Focus of DRYLAND CEREALS in overall research structure of the CGIAR (figure from CGIAR Strategy and Results Framework)

OVERVIEW OF DRYLAND CEREALS STRATEGIC OBJECTIVES

CRP 3.6 is organized around six interrelated Strategic Objectives, which themselves rest logically on the central challenges and/or opportunities described in the Program Justification section. A brief overview of these Objectives is provided below, along with major outputs to be produced. An in-depth description of each Strategic Objective follows this brief overview.

Strategic Objective 1 – Better targeting of opportunities for technology development and delivery of dryland cereals to smallholder farmers in Africa and Asia

Together with CRP 2, Strategic Objective 1 aims to develop information resources required for better targeting of DRYLAND CEREALS research efforts. An information system will be designed to track the introduction, adoption and impact of dryland cereal technologies. Indicators of adoption and impact will be developed, and a flexible M&E system will be implemented that will facilitate critical reflection, learning and feedback. Key partners will be trained in standardized survey design and data collection methods, project M&E, and analysis of the dynamics of adoption and impact.

Major Outputs:

1.1. Knowledge and priorities for R4D opportunities along the dryland cereals value chain to increase benefits to smallholder farmers, especially women

1.2. Knowledge of trade-offs between food and non-food uses of dryland cereal multipurpose varieties and hybrids

1.3. Evidence for policy and regulations to increase demand and supply of dryland cereal grain and processed products

Strategic Objective 2 – Enhancing the availability and use of genetic diversity, genomics and informatics to enhance the efficiency of dryland cereal improvement

This Objective is designed to more fully document the wide range of genetic diversity found in publically available collections of dryland cereal germplasm to facilitate development of more productive varieties (Strategic Objective 3) that have improved stability of production, better storage characteristics, improved nutritional quality, and enhanced value for multiple uses, such as for grain and fodder or using stover and straw as construction materials. The work that will be done under this objective is needed to ensure that diversified dryland cereal varieties are available to farmers over the longer-term. This diversification will provide them with viable options for increasing the availability of food grain with preferred traits under a range of production conditions, and increase the resilience of farming systems in anticipation of climate change impacts.

Major Outputs:

- **2.1.** Dynamic dryland cereal germplasm conservation, exchange and utilization
- **2.2.** Characterized dryland cereal genetic resources for key traits and future use
- **2.3.** Integrated breeding platform for more efficient breeding

Strategic Objective 3 – Developing improved dryland cereal varieties and hybrids for increased yield, quality and adaptation in smallholder farmers' fields

The work planned under this Strategic Objective is focused on using in creative ways the very wide genetic diversity found in dryland cereals, between and within species, to develop new, higher yielding varieties with improved tolerance for abiotic stresses and resistance to biotic pests. These varieties will have greater yield stability and will express farmer-preferred quality traits that increase household food security, nutrition and/or income via new marketing opportunities for these cereals or products derived from them. Products from this research will be well-adapted and more productive hybrid parents, varieties and hybrids. At the same time, the methods and tools used for variety development will be analyzed and documented so that crop breeding efficiency and effectiveness can be improved across crops, regions and traits.

Major Outputs:

- **3.1.** High grain and fodder yielding varieties and hybrids with desired end-user quality attributes
- **3.2.** Varieties and hybrids with better tolerance to heat, drought and low soil fertility
- **3.3.** Varieties and hybrids with improved resistance to diseases and pests
- **3.4.** Varieties and hybrids with enhanced green forage, stover and straw varieties for fodder and other uses
- **3.5.** Varieties and hybrids with enhanced grain qualities for food, feed and industrial uses

Strategic Objective 4 – Developing sustainable crop, pest and disease management options to capture genetic gains from improved dryland cereal varieties and hybrids

This Strategic Objective will target the development of crop management options that contribute to increased cereal yields and quality. The options produced will be affordable and meet the requirements of smallholder farmers. The interventions will exploit genetic yield potential and will include nutrient application, seed priming, and integrated management strategies for biotic and abiotic constraints (IPM/IDM). In addition, information will be generated for breeders regarding desirable traits and plant types for low fertility, variable rainfall conditions and different farming systems. Many of these crop management activities will be done in conjunction with CRP 1.1 to ensure that interventions are based on knowledge of and experience with dryland farming and livelihood systems.

Major Outputs:

- **4.1.** Gender responsive crop management options to optimize crop productivity in smallholder farmers' fields
- **4.2.** Integrated *Striga*, disease, pest and weed management options to meet the social, environmental and ecological sensitivities of dryland cereals

Strategic Objective 5 – Enhancing effective seed and information systems for better delivery of improved technology packages to smallholder farmers

Focused on research related to improving the effectiveness and efficiency of seed and information delivery systems, Strategic Objective 5 will identify viable ways to enhance the availability of improved technologies (e.g. seed and agronomic practices) to smallholder farmers in Africa and Asia. Weak seed production and delivery systems (both formal and informal), coupled with high prices for and poor availability of fertilizers, and limited awareness about new technologies and provision of relevant information combine to inhibit the use of technologies that can increase the productivity and production of smallholder dryland cereal producers. Government policies occasionally adversely affect input delivery systems, and extension services generally must focus their limited resources on farmers in more favorable environments, giving scant attention to those in marginal dryland systems.

Major Outputs:

- **5.1.** Integrated crop and management technology packages for dryland cereals
- **5.2.** Innovations to strengthen seed and input delivery systems for smallholder farmers
- **5.3.** Better communication and knowledge sharing options for improved awareness and use of dryland cereal technologies

Strategic Objective 6 – Adding post-harvest value and improving market access of dryland cereals to provide smallholder farmers more benefits from dryland cereals

This Objective targets identifying and developing options for producing value-added products from dryland cereals. Smallholder farmers, especially women, can benefit from value-adding post-harvest activities and enterprises, as well as better market access. The first and most widespread opportunity rests on the integration of food and fodder, and possibly feed production. If they have desired qualities, and are available when demand is high, fodder and feed can become a valuable marketable surplus. Processing options that maintain and add value to dryland cereals in food processing value chains will be identified, and appropriate business models will be adapted for marketing newly developed dryland cereal food products. Special attention will be given to determining what is required for smallholder farmers, especially women, to reliably supply high quality grain to the food industry at competitive prices.

Major Outputs:

- **6.1.** Improved storage and processing technologies to reduce post-harvest losses in quantity and quality
- **6.2.** Novel and diverse dryland cereal-based products to stimulate demand grain
- **6.3.** Institutional innovations to improve linkages between smallholder farmers and markets

LINKAGES AMONG STRATEGIC OBJECTIVES

These six Strategic Objectives are closely linked (Figure 4). Strategic Objective 1 supports and helps to focus the other five Strategic Objectives on relevant geographic areas and particular challenges facing smallholder dryland cereal farmers in our target farming systems. Strategic Objective 2 supports DRYLAND CEREALS commodity development work by ensuring the availability of and access to genetic resources containing traits important to smallholders, to facilitate the more efficient creation of diverse varietal options (and hybrids) with modern breeding approaches, and to increase the resilience of target farming systems. It also contributes to breeding work aimed at producing multiple use varieties (fodder and feed) needed to support the livestock revolution, and to increase smallholder productivity and food security in general. Strategic Objective 3 draws on the research outputs of Strategic Objectives 1 and 2 to improve the efficiency and effectiveness of dryland cereal breeding work, and partners with Strategic Objectives 4, 5 and 6 to make sure the varieties and hybrids being produced have not only high yield potential and better disease resistance and abiotic tolerances, but also meet other farmer preferences for quality, management, post-harvest handling and processing. Strategic Objective 3 will also evaluate and document the approaches and breeding tools being used so that breeding efficiency and effectiveness can be improved across crops, regions and traits. Strategic Objective 4 is centered on generating viable crop management options for harsh environments that will get the most out of the new dryland cereal varieties and hybrids being produced, and optimize smallholder production, productivity, and profitability to encourage adoption. Strategic Objective 5 is focused on identifying constraints to the delivery of seed, information and other inputs to dryland smallholders, and devising feasible options for addressing them. And Strategic Objective 6 will investigate opportunities for adding post-harvest value to dryland cereals, especially for women, and increasing access to local and regional markets. Capacity strengthening of various kinds will cut across all the Strategic Objectives, as will efforts to ensure gender mainstreaming in our work to meet the specific needs of women farmers – as well as draw on their experience, knowledge and skills relative to producing, processing and marketing dryland cereals.

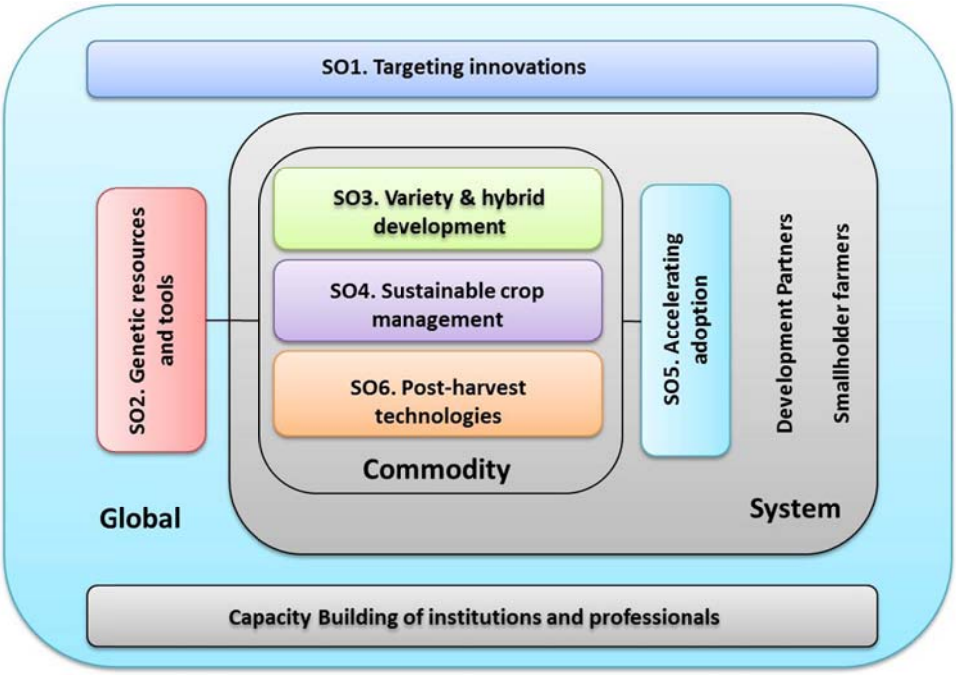

Figure 4. Linkages among DRYLAND CEREALS Strategic Objectives

Each of the DRYLAND CEREALS Strategic Objectives is described in more detail below, and especially in Appendix 4. The rationale for and major lessons learned about each are presented, as well as the process used to establish research priorities. An impact pathway for each Strategic Objective is presented that illustrates how research outputs lead to products, research outcomes, development outcomes and impacts. Key partnerships are briefly discussed, but a more detailed presentation (including the roles of partners in producing or contributing to specific outputs) is included in Appendix 4. Gender issues specific to each Strategic Objective are discussed, and innovations that pertain to the research being done are identified. Outputs and milestones (2012-2014) are outlined below, and then presented in more detail in Appendix 4, along with the methodologies that will be used to produce them.

Strategic Objective 1: Better targeting of opportunities for technology development and delivery of dryland cereals to smallholder farmers in Africa and Asia

Rationale and Description

In close collaboration with CRP 2, Strategic Objective 1 will develop the information resources required for better targeting of the DRYLAND CEREALS research program and for exploiting opportunities to promote appropriate technologies and innovations. Specifically, this Objective will develop an information system to track the introduction, adoption and impact of proven dryland cereal technologies in primary target and secondary diffusion areas in Africa and Asia. It will identify indicators of adoption and impact in terms of productivity, equity, income, profitability and food and nutrition security that need to be tracked. It will design and implement a participatory, innovative and science-based monitoring and evaluation system that will allow critical reflection, learning and feedback. The impacts of early adoption of technologies and innovations will be monitored and documented using multi-dimensional indicators. The capacity of all partners will be enhanced through training in survey design and data collection methods, project monitoring and evaluation and analysis of dynamics of adoption and impact of dryland cereals

Agricultural research institutes the world over have developed crop improvement and management technologies and innovations targeting rainfed agriculture. However, these technologies and innovations often do not reach smallholder farmers due to a lack of effective delivery mechanisms. Thus adoption remains low, and is further constrained by limited access to capital, poor infrastructure, weak linkages between producers and input and product markets, and a lack of appropriate policy support.

Interventions for improving productivity and/or reducing production risks for dryland cereal farmers will be more effective with better characterization and targeting of production environments, stress factors, markets, and the profiles of target farmers. This targeting will be based on secondary information regarding: geographic areas, production and productivity levels; the extent of adoption; priority preferences (i.e. of farmers, consumers and other end users) along the value chain; utilization and marketing; and past efforts to introduce new technologies and the lessons learned from those efforts. GIS tools will be used to develop maps of target areas for technology delivery and diffusion, and situation and outlook reports will be prepared for dryland cereals in the WCA, ESA, CWANA, and SA regions.

There is still limited understanding of the trade-offs producers place on both food and feed in different regions. In addition, under the right circumstances the development and introduction of locally adapted hybrids will offer increased productivity over OPVs. Thus, there is a need to better understand the trade-offs for smallholder farmers and the potential of hybrids to not only increase yields, but to attract the private sector in order to ensure remunerative returns to the smallholder farmers. To increase returns to investments in R4D, it is necessary to give priority to options that will provide the highest benefits. *Ex-ante* analyses of potential impacts from the introduction of proven technologies and delivery alternatives should be conducted. This will provide the information needed to select and target the most promising opportunities. When complemented by well-designed monitoring and evaluation systems, impact will be increased through greater success in technology development, innovation and adoption.

Lessons Learned

Key lessons have been learned from past targeting and evaluation efforts:

- The adoption of improved technologies by smallholders lags significantly behind its development. Adoption tracking requires disaggregation of adoption pathways of smallholders versus large-scale farmers to be able to delineate delays and the magnitude of benefits that accrue to smallholders relative to larger scale farmers.

- The Sorghum and Pearl Millet Improvement Program undertaken in SADC during the mid-1980s to the early 2000s concluded that “champions” and collective action in seed multiplication enables a sustained uptake of improved seed technologies.
- Smallholder farmers value the multi-purpose uses of dryland cereals, especially in West Africa. Dryland farmers are both crop producers and livestock raisers, and new varieties that do not embody multiple traits are not likely to be adopted. This is also the case for South Asia. In India, farmers have been reluctant to adopt improved sorghum varieties grown in the post-rainy season because of low grain and fodder quality traits. It is therefore necessary to simultaneously improve food/feed traits to make new cultivars attractive to smallholder farmers.
- In the case of pearl millet in West Africa, varieties that have short, thin stalks have been rejected, as have varieties that have been used to produce processed products with short shelf lives. In Asia, pearl millet grain that cannot be stored and that produces flour that turns rancid after only a short time is likely to be rejected by farmers. Thus, there is a need to increase the shelf life of grain and reduce certain undesirable attributes, such as fat content and phenolic compounds, which will improve the shelf life of the flour.
- During the last 30 years, governments and donors have invested more than US$ 200 million in the development of seed systems in WCA. These efforts have produced little impact; formal systems still supply less than 1% of commercially used seed. However, for dryland cereals, the development of seed systems has relied largely on OPVs and the private sector has as a result shown little interest to invest because of limited potential for profits. This led to the emergence of community based seed systems, but these have proven to be unsustainable.

Priority Setting

The *ex-ante* analysis of potential benefits of the broad set of alternative options in the dryland cereals research portfolio is an essential component of this Strategic Objective. This component will determine the range of opportunities for achieving research benefits while targeting different crops and crop types with alternative uses as food, feed, fodder and fuel. Participatory priority setting efforts will involve scientists who will provide knowledge about potential technologies and associated gains; public and private sector stakeholders and ultimate beneficiaries (farmers) will provide perspectives on multi-use traits and trade-offs among competing research opportunities.

A top priority for Strategic Objective 1 will be to systematically define and develop measurable indicators that correspond to all six DRYLAND CEREALS Strategic Objectives. The effectiveness of research investments in specific dryland cereal crops, traits and productivity constraints will be evaluated, using measures that enable the comparison of benefits among competing research objectives as well as measurement of tradeoffs among multiple-use traits.

Strategic Objective 1 research priorities will be based on the relative valuation of traits, and the trade-offs between traits, by smallholder farmers, the private sector (e.g. food/feed/energy processing industries – bakeries, breweries, and poultry and cattle feeders) and consumers. Food and feed traits will be identified and prioritized, and researchers will focus on the improvement of varieties/hybrids incorporating those traits. Desired traits will normally be site specific, and influenced by such factors as farmers’ socio-economic and demographic profiles, biophysical environments, and institutional and policy considerations that can limit (or promote) adoption of new technologies. Food and livestock value chain analyses aimed at increasing efficiency, reducing transaction costs, and estimating the value added at different stages will also be a high priority research activity under Strategic Objective 1.

Impact Pathway

Strategic Objective 1 outputs and their associated products will lead to several research and development outcomes and, eventually, impacts (Figure 5). Enhanced knowledge of smallholder farmer preferences regarding improved varieties and hybrids suitable for food, feed, processing, and industrial use will lead to increased seed replacement and adoption of improved technologies. Changes in cropping patterns towards sorghum and millet for industrial uses will lead to higher incomes. Enhanced forward and backward linkages between producers and other actors in the value chain will lead to reduced transaction costs and better participation of service providers, such as input dealers, commercial and cooperative banks, private firms, and NGOs. Better, evidence-based policies will help stimulate demand for dryland cereals for different uses and contribute to increasing private investment. Knowledge about value addition options that is generated as new processing options are developed will both facilitate their adoption and use, as well as joint priority setting by program partners leading to inclusive growth. Institutional innovations that increase market access and demand will encourage adoption and the increased production, productivity and profitability of dryland cereals in our target regions. This will in turn improve household food and nutritional security and contribute over time to a much needed transition to increasingly market-oriented dryland cereal economies that enhance livelihoods of the very poor.

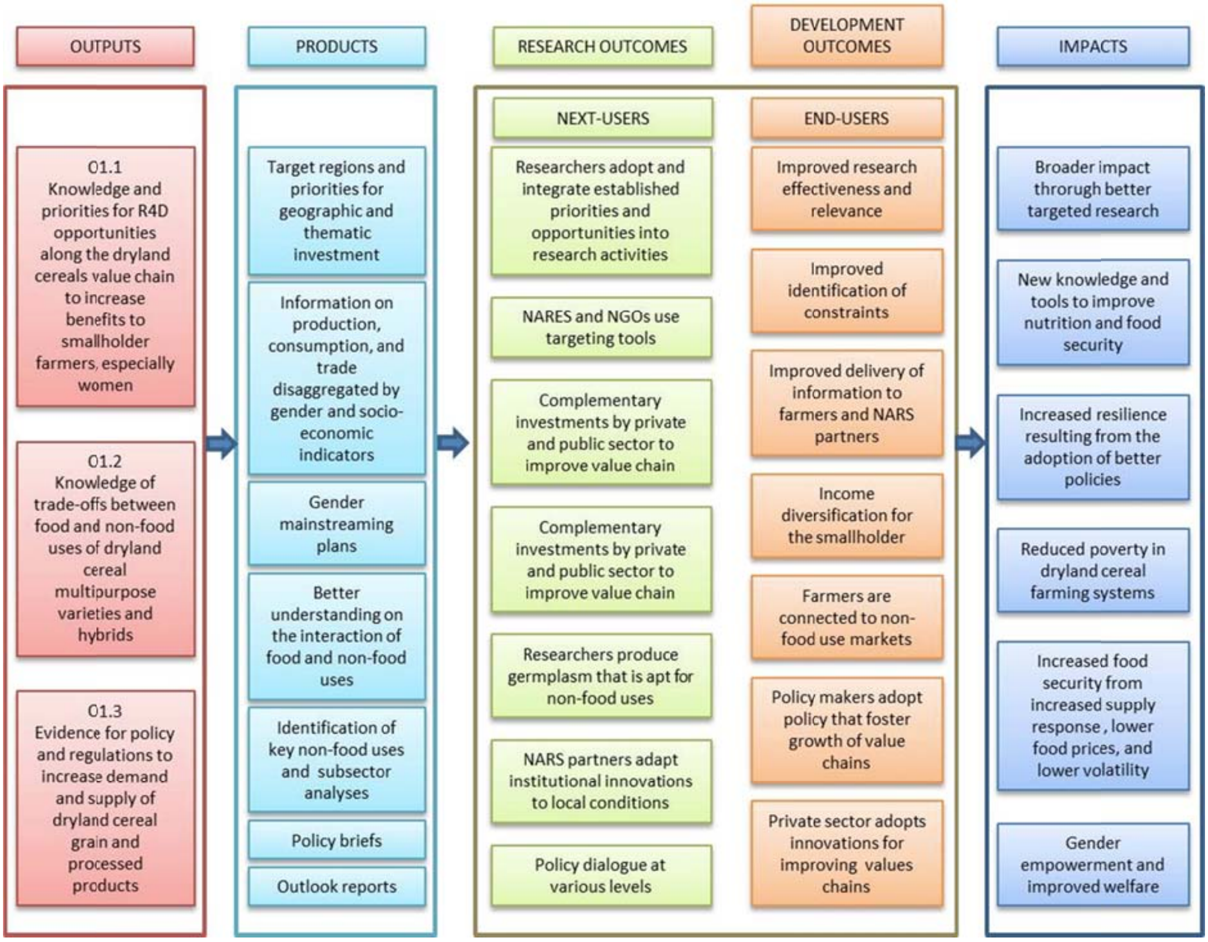

Figure 5. Strategic Objective 1 impact pathway

Key Partners

A number of major partners will be involved in producing Strategic Objective 1 research outputs (Appendix 4 for more details). Groups and organizations engaged in monitoring and evaluation and impact assessment will be engaged, as will experts from various disciplines to ensure the effectiveness of the envisioned participatory process involving stakeholders across the dryland cereals value chain. Also, partners with special competencies in using advanced research tools, including GIS and spatial analysis, as well as in data management and warehousing will be involved. Local entities, such as well-established and emerging farmers' associations, will play important roles in identifying farmers' needs and opportunities in specific zones or regions. Development organizations working to improve crop productivity and sustainability in dryland areas, private (commercial) businesses that need dryland cereals to produce products for end users (such as breweries), and service and input providers will all be essential partners under Strategic Objective 1.

Gender Strategy

Because women and men often have different but complementary roles in crop production through to consumption, they have different needs, priorities and knowledge related to traits and crops that must be taken into account by households when adopting new technologies. To increase adoption rates of improved varieties and practices, it will be important that the gender-differentiated needs of all farmers involved along the food chain are documented and used to inform breeding strategies.

Strategic Objective 1 will thus mainstream gender-disaggregated data collection and analyses on the roles of women and men in dryland cereal value chains. Gender-sensitive data collection methods, such as the use of female enumerators, will be employed to elicit information on gender-sensitive issues. Special training programs to enhance the skills of women farmers in such areas as post-harvest handling, agro-processing value addition, and small agri-business entrepreneurship will be conducted. Gender perceptions on quality attributes of grain and fodder, and tradeoffs between food and non-food uses of grain will be assessed. The institutional arrangements for active participation of women groups from seed to final product in the value chain will be analyzed. The economic viability of different options for linking smallholder women's groups to various service providers will also be analyzed. Welfare implications of drudgery-reducing technologies will be evaluated with an eye towards scaling them up.

Gender-disaggregated baseline data will be collected. Questions will be framed differently for women and men so as to capture a clearer picture of the perceptions, roles and preferences among women and men within households. Strategies for improving livelihoods and empowering women will be designed taking into account gender-disaggregated data. Such data will also be collected relating to gender roles in markets, access to inputs and new technologies, and value addition. DRYLAND CEREALS research will increase awareness of gender-based constraints and opportunities by expanding the range of gender-disaggregated data and socioeconomic models and the use of gender analysis in research in semi-arid tropical agriculture. In particular, value-chain work will identify ways of ensuring that commercialization in crop production does not transfer control from women to men, and that the representation of women throughout the value chain and critical impact pathways is strengthened. The enhanced learning through partnership-based innovations in R4D will help strengthen the roles of ICRISAT, ICARDA and other key partners in policy dialogue and advocacy.

Innovations

Strategic Objective 1 will capitalize on new science tools to capture data, including computer-assisted processing instruments (CAPIs) for gathering ongoing M&E information; PRA innovations to regularly complement the baseline and monitoring farm surveys on adoption and real-time intermediate impacts; and a project portal using cloud computing that effectively serves as a platform for disseminating and retrieving data. Partners with competencies in new science tools will be strategically involved for spatial analyses (e.g. ESRI, aWhere and the GIS unit at CIAT), and data management and warehousing (Microsoft or other resources) to enhance research efficiency in economic and social analysis, synthesis, documentation and data dissemination.

Outputs and Milestones for Strategic Objective 1 (Appendix 4)

1.1 Knowledge and priorities for R4D opportunities along the dryland cereals value chain to increase benefits to smallholder farmers, especially women

Detailed analyses of the costs and returns for individual dryland cereal value chains will help to identify where to invest, what to improve, what kinds of innovations are needed, and what the real opportunities are for R4D to have sustainable and beneficial impacts, particularly for women farmers.

Milestones

- Mainstreamed gender plans for dryland cereals (2012)
- Identify end market opportunities for dryland cereals (2013)
- Completed Value Chain Analysis for two crops in two countries per region (2014)

1.2 Knowledge of trade-offs between food and non-food uses of dryland cereal multipurpose varieties and hybrids

Alternative uses of dryland cereals create new opportunities that have potential to increase market demand and income for smallholder farmers. We need to know more about farmers preferences and decision making relating to a) the varieties/hybrids incorporating the quality attributes preferred by them for consumption or industrial use, b) improving keeping quality of the flour and exploring health benefits and nutraceutical value, c) exploring non-conventional uses and extrusion products, and d) nutritional value.

Milestones

- Identification of key non-food uses in region/country for target crops (2012)
- Completed analysis of one subsector in each region (2013)
- Completed analysis of willingness to pay for hybrid seed in Nigeria and Niger (2014)

1.3 Evidence for policy and regulations to increase demand and supply of dryland cereal grain and processed products

While productivity improvements have been achieved over the years, a lack of economic incentives and effective demand has adversely affected the willingness of risk-averse smallholder farmers in dryland areas to adopt new technologies. Evidence suggests that barley, millets, and sorghum can substantially contribute to food, nutritional, and economic security of these farmers, but that appropriate policies need to be developed and put in place to stimulate effective demand for these crops.

Milestones

- Outlook Report for dryland cereals for each region (2012)
- One Policy Brief for each region disseminated to policy makers (2013)
- Measure the efficiency and competitiveness of dryland cereals (2014)

Strategic Objective 2: Enhancing the availability and use of genetic diversity, genomics and informatics to enhance the efficiency of dryland cereal improvement

Rationale and Description

Genetic variability for economically important traits, and the tools needed to effectively manipulate such variability are keys to the success of any crop improvement program. Strategic Objective 2 will enhance the effective exploitation of the very wide range of genetic diversity found in public collections of dryland cereals to facilitate development of more productive varieties, with improved stability of production, storage characteristics, and with enhanced value for multiple uses like grain and fodder or construction materials combined and improved nutritional quality. It will achieve this by:

- Ensuring reliable conservation and availability of dryland cereals genetic resources;
- Identifying and filling gaps in existing *ex-situ* collections;
- Enhancing access to information on the contents of existing collections;
- Enhancing, better characterizing and disseminating representative subsets of these collections that provide cost-effective entry points for use in identifying novel favorable variation for traits of economic importance from existing collections;
- Strengthening tools for mining allelic diversity from wild and cultivated gene pools of these dryland cereals;
- Enhancing screening methods for complex traits, such as
  - Tolerance to abiotic stresses,
  - Resistance to biotic production constraints, and
  - Product quality;
- Establishing platforms integrating conventional and molecular plant breeding approaches; and
- Assessing pre-breeding approaches to move new variation for economically important adaptation and quality traits into genetic backgrounds readily accessible to dryland cereal programs globally.

These activities will ensure the continuous flow of genes needed for longer-term effectiveness of dryland cereals in breeding genetically diverse varieties for farmers in our target areas. Access to such varieties will give farmers options for improving the availability of food and feed grain that has the traits they prefer, and do so over a range of production conditions. The economic uses of these resilient crops will also be diversified in anticipation of increased impacts from climate change.

Lessons Learned

Several key lessons have been learned from past research efforts:

- Applying best practices will ensure long-term conservation and continued availability of genetic resources;
- To be effectively exploited by breeders, germplasm characterization data sets require curation to correct obvious errors, and therefore better database management tools need to be implemented;
- Using core/minicore/reference collections (Caniato et al., 2011) and Focused Identification of Germplasm Sources (FIGS) (El Bouhssini et al., 2010) result in efficient characterization and evaluation of large germplasm collections to identify sources of desirable traits;
- Enhancing the quality of passport data increases the value of collections for future use;
- Applying genetic marker-based diversity analysis is a rapid and effective way of grouping germplasm accessions, including those of unknown origin;

- Genetic transformation technologies provide additional avenues for increasing genetic diversity for complexly inherited traits, and for validating the role of specific genes in controlling such traits, but are still politically sensitive in many regions;
- Phenotypic characterization of germplasm within a phenological/adaptation group is more meaningful than characterizing random samples/minicore collections, although the latter provide efficient ways to identify specific germplasm groups for more detailed phenotypic evaluation;
- There is a need to strengthen the capacity of partners to improve their understanding of ITPGRFA/SMTA regulations and increase their appreciation for the necessity and value of germplasm sharing through this international treaty; and
- Regional gene banks facilitate more dynamic germplasm sharing and effective utilization, complementing centralized gene banks.

Priority Setting

New collection missions will give highest priority to collecting landraces and wild relatives in dryland cereal gene pools. Primary and secondary centers of diversity that are subject to the rapid loss of biodiversity will get priority attention from new collection missions. Priority regions for these missions will be defined through gap analyses to cover the geographic distributions of each species and/or to target accessions containing specific valuable traits. In the case of barley, the focus will be on landraces and the two *Hordeum* wild species (*H. spontaneum* and *H. bulbosum*), while for sorghum the focus will be on wild sorghums from the secondary gene pool that have potential as sources of high levels of insect resistance. The traits desired by farmers and consumers will guide breeding efforts, and will thus be the priority traits sought in conserved genetic resources. Adaptive traits critical for future climate change will be given priority, as will quality traits that will enhance food and feed uses and sources of resistance to major diseases and insects.

In terms of improving quality of and access to passport, characterization, phenotype and genotype data sets associated with dryland cereals germplasm collections, we will give priority to updating location data, assessing the potential of GrinGlobal as a management and information resource, and establishing crop registries for each of the dryland cereals.

For genetic transformation technologies for dryland cereals, priority will be given to their development and possible use as functional genomics tools (to validate the roles of specific genes in particular traits of interest), and to refinement of transformation protocols to the point that they could deployed without delay to enhance useful genetic diversity of dryland cereals.

Minicore, reference and FIGS sets will be refined, and promoted as cost-effective entry points to the larger DRYLAND CEREALS germplasm collections, for identification of sources of traits, establishment of marker-trait associations, and allele mining. Extensive evaluation of these subsets, combined with archival of phenotyping datasets in readily accessible form, will be given priority over routine single-site assessment of larger numbers of accessions that necessarily confound genotype and environment effects. As pearl millet is the only largely cross-pollinated crop among the dryland cereals, and its breeding behavior makes it more difficult to perform such association mapping studies because of the large proportion of within-accession variation, an inbred association panel will be established for this cereal so that it, too, benefits from the opportunities available for identifying marker-trait associations based on replicated phenotypic observations of genetically uniform accessions having high-density genetic fingerprints.

Priority traits for evaluation in these germplasm collection subsets will be those required by dryland cereal producers and consumers in the highest priority production systems for each crop in each region (Strategic Objective 3). Priority will be given to traits that are critical to food security, improved nutrition, and reduced drudgery for women and children, for which potential gender benefits are clear. Therefore, traits associated with yield performance, yield stability, and product quality in the regionally prioritized production systems for each of the dryland cereals will be given priority. For example, in pearl millet, stemborer is primarily a problem in the Cereal and Root Crop System (which has not been identified as highest priority for pearl millet in WCA) and so would be given lower priority as a target trait than *Striga* resistance, which is required across all production systems in which this crop is grown in WCA. Further, due to the inherently greater difficulties in evaluating heterogeneous accessions varying in their level of inbreeding, preference for phenotyping for association mapping would be given to screening subsets of the primarily self-pollinated dryland cereals (barley, finger millet and pearl millet) until such time as an appropriate inbred association panel is available for pearl millet. Similarly, low priority would be given to evaluation of pearl millet for water conservation traits for the high priority Pastoral and Agro-pastoral Systems in WCA, as the predominance of sandy soils with low water retention capacity renders such drought-tolerance mechanisms ineffective there.

Once improved high-throughput phenotyping platforms are available for dryland cereals, priority for their use will be given to well-characterized experimental populations of use in trait mapping and gene discovery (such as minicore, reference or FIGS sets).

Similarly, priority will be given first to exploratory use of the GCP Integrated Breeding Platform, via proof-of-concept projects including the on-going sorghum MARS and BCNAM projects, rather than independent development of such a platform. Priority will also be given to enhancing the capabilities of ICARDA's and ICRISAT's dryland cereals breeding programs, as well as the more applied breeding programs of our NARES partners, to use the IBP to appropriately increase their use of molecular and information technologies as breeding tools, initially through proof-of-concept projects.

Impact Pathway

The three outputs that will be produced under Strategic Objective 2 will lead to products useful for generating research and development outcomes, which in turn will lead to measurable impacts (Figure 6). In the context of Strategic Objective 2, efforts will be targeted on enhancing:

- Existing germplasm collections of DRYLAND CEREALS and their wild relatives;
- Content and access to databases (of passport as well as phenotypic and genotypic data) associated with these collections (Dwivedi et al., 2011);
- Cost-effective access to these collections;
- Screening protocols for complexly inherited traits of economic value; and
- Platforms for more effective integration of conventional and molecular plant breeding approaches.

This will make genetic improvement of dryland cereals for target environments more efficient and effective in addressing the needs of producers and consumers of grain, biomass and crop residues from these crops. The primary consumers of Strategic Objective 2 outputs will be public- and private-sector dryland cereal crop improvement scientists, including plant breeders, molecular biologists, stress physiologists, pathologists, entomologists, and weed scientists, as well as scientists focused on economic uses of dryland cereals as a means of generating economic value – all of whom will benefit from more efficient systems to tap the economic value that is contained in genetic resource collections of these crops. These primary consumers will in turn contribute more directly to dryland cereal varietal enhancement and diversification in Strategic Objective 3. When farmers adopt the resulting superior, genetically diverse, and locally adapted cultivars, dryland cereal cultivation will become less risky and more profitable, resulting in enhanced food and nutritional security and lower consumer prices. The ultimate goal is to contribute to food and feed production increases to sustain the livelihoods of resource-poor farmers in our target areas and farming systems.

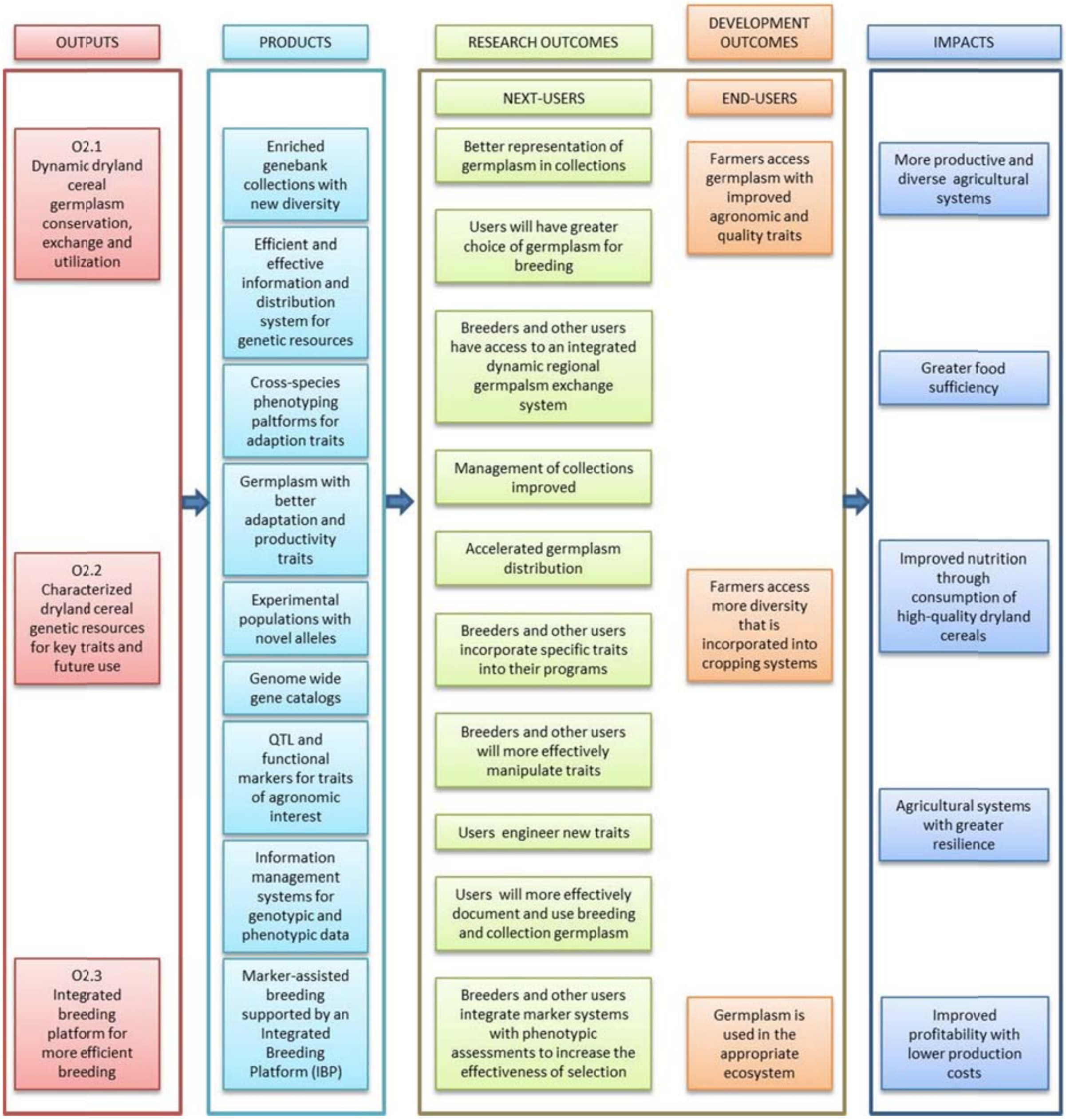

Figure 6. Strategic Objective 2 impact pathway

Key Partners

A number of partners have been identified that will contribute to the delivery of specific outputs. ICARDA and ICRISAT will contribute to all of the Strategic Objective 2 outputs, but other public and private organizations will make important contributions to specific outputs according to their relative comparative advantages. The partnerships we envision range from working with private malting companies to select and test new malting varieties of barley, to conducting joint research with public sector organizations on disease resistance and various abiotic tolerances. Advanced research institutes in the developed and developing world will bring new technologies to bear on persistent breeding challenges, as will selected universities with expertise in relevant genomics and genetic characterization techniques (Appendix 4).

Gender Strategy

Strategic Objective 2 will focus on improving the range of genetic variation and the selection protocols used by dryland cereal breeding programs to develop improved cultivars that open market opportunities to benefit women, particularly opportunities that lead to their empowerment and improve their livelihoods. Traits relating to nutrition and food security are especially relevant to women, as are those that improve feed and fodder quantity and quality, as women often care for household livestock. Improved technologies that make it easier for women to process food for home consumption, and to process it in larger quantities for storage and for sale in the market, can help reduce drudgery and the workload handled by women. Therefore, in large part trait-specific research in this CRP will focus on traits that are critical to food security, improved nutrition and reduced drudgery for women and children:

- Abiotic stress tolerance and biotic stress resistance that enhance food security by improving the stability of production;
- Better crop-establishment characteristics that enhance food security; and
- Enhanced food processing and storage characteristics, as well as nutritional quality.

Innovations

Strategic Objective 2 will produce and/or capitalize on a number of innovations, including:

- Better access to data and information on phenotyping and genotyping of representative and targeted samples from global collections of dryland cereal germplasm;
- Linking genetic resources information to the GCP molecular breeding platform;
- High-throughput, high-precision phenotyping;
- Crop models incorporating allele-specific coefficients to assess potential utility of candidate target traits, genes and alleles;
- Gene discovery and allele mining that exploits appropriate association panels, TILLING and Eco-TILLING populations, and genotyping-by-sequencing approaches;
- More effectively integrating MAS and genome-wide selection as applied tools in breeding programs;
- Tapping secondary and tertiary gene pools of dryland cereals to access useful alleles not present in cultivated materials;
- Applied use of transformation/transgenics as tools for gene discovery, increasing genetic diversity, and cultivar improvement;
- Enhanced efficiency of doubled haploid production as a tool for speeding derivation of inbred lines of finger millet, pearl millet, sorghum, and barley (this is already used in breeding barley and becoming increasingly common in breeding maize);
- Greater exploitation of genetic sterility as a tool to assist in the production of large segregating backcross populations to reduce the number of generations required for marker-assisted introgression of diversity and/or specific traits into elite, adapted, market-preferred genetic backgrounds for specific target regions;
- Integrated application of modern tools – molecular, quantitative, modeling, and participatory – for targeted use of local and regional crop diversity. Molecular markers will be used to better understand the diversity existing in each region. We will identify markers associated with resistances to main biotic stresses (e.g. blast and *Striga* for finger millet, downy mildew, blast and *Striga* for pearl millet, shoot fly and *Striga* for sorghum, net and spot form of net blotch, scald and stripe rust in barley) and use them to aid breeding efforts to combine and pyramid resistances using MAS and GWS; and
- Establishment of community of practices for better adoption of new technologies in breeding programs of NARS.

Capacity Strengthening
One of the lessons we have learned from past efforts is that strengthening the capacity of partners in the use of modern tools and techniques is an ongoing process. Relative to Strategic Objective 2, we will:

- Train scientists and students (MSc, PhD) in new technologies, and their integration with cost-effective conventional breeding methods;
- Help educate scientists and research managers as to the importance and application of the ITPGRFA, and the SMTA that is required for its implementation; and
- Strengthen applied breeding capabilities in national programs in concert with (or as a foundation for) using biotechnological methods as tools for variety development and deploying new biotechnology-based products.

Outputs and Milestones for Strategic Objective 2 (Appendix 4)

2.1 Dynamic dryland cereal germplasm conservation, exchange and utilization

The focus here is on determining the status of existing germplasm collections and related data of barley, finger millet, pearl millet and sorghum, as well as documenting their exchange among the principal dryland cereals partners, i.e., national, regional and international research institutes, NARES, public and private sector seed companies, NGOs, farmers and other individuals to enrich the existing collections globally.

Milestones
- Location data (latitude and longitude) updated for all DRYLAND CEREAL accessions in ICARDA and ICRISAT genebanks (2012)
- GRIN-Global implemented as a global DRYLAND CEREAL management and information resource (2012)
- Mini core, reference and/or FIGS sets of DRYLAND provided to partners for evaluation in stressful environments and assessment of quality traits (2012)
- Reference sets and minicore collections of DRYLAND CEREALS updated (2013)
- Crop registries for DRYLAND CEREALS genetic resources developed and gaps in existing *ex-situ* germplasm collections of barley, finger millet, pearl millet and sorghum identified (2013)
- DRYLAND CEREAL germplasm collection missions completed in priority areas in Africa and Asia to fill gaps and to collect trait-specific germplasm (2013)
- Pearl millet inbred germplasm association panel developed, conserved and available for dissemination (2014)

2.2 Characterized dryland cereal genetic resources for key traits and future use

This output will deliver novel sources of genetic variation to enhance productivity, production stability, and product quality of grain and crop residues from dryland cereals. Exploiting existing germplasm resources, new approaches to identifying the genes underlying phenotypic variation will focus on traits having the greatest potential for improving crop performance across sites and over time.

Milestones
- Re-sequencing and genotyping-by-sequencing (GBS) approaches identify more than 1 million single nucleotide polymorphism (SNP) markers in sorghum (2012)
- Publically available DRYLAND CEREAL association panels, TILLING populations, MAGIC populations and bi-parental mapping populations inventoried, priorities for their assembly in ICARDA and ICRISAT gene banks determined, and likely costs for their assembly estimated (2012)
- Phenotyping network established for DRYLAND CEREALS across partners and crops (2012)

- Effective field phenotyping methods for adaptation to low-P identified (2013)
- Sorghum backcross nested association mapping (BCNAM) populations available for evaluation in genetic backgrounds for two production systems in WCA (2013)
- Recessively inherited genetic male-sterility backcrossed (to BC1) into backgrounds of at least five genetic genetically diverse, agronomically elite cultivars of barley, finger millet and sorghum for each priority target production system as tool for genetic diversification (2013)
- High-throughput phenotyping platform, including imaging facility (infra-red and RGB imaging), based on existing lysimeter facility established at ICRISAT-India (2014)
- Draft genome sequences produced for additional DRYLAND CEREALS (2014)
- Protocols to screen for resistance to blast in finger and pearl millet, and aphids in sorghum refined and shared with NARS; and protocols to screen barley for resistance to barley gall midge established (2014)
- At least ten new sources of resistance to downy mildew, blast, and head miner in pearl millet; grain molds, foliar diseases, shoot fly, and aphids in sorghum; major diseases and insect pests in barley, and blast in finger millet identified and distributed to NARS (2014)
- Mini core and reference collections of pearl millet, sorghum, and finger millet evaluated against key biotic and abiotic stresses and for quality traits (2014)

2.3 Integrated breeding platform for more efficient breeding

The power of genomics, up-to-date information technology, and systems biology enable large increases in the efficiency of dryland cereal research and breeding efforts, and offers an opportunity for the entire CRP to exploit new opportunities through advanced science.

Milestones

- Analysis pipeline for genotyping-by-sequencing data implemented at ICRISAT (2012)
- New marker-based breeding projects initiated with national breeding programs and links with Integrated Breeding Platform facilities established (2013)
- Marker-assisted recurrent selection (MARS) demonstrated in sorghum (2013)
- Genome-wide selection (GWS) method evaluated for at least for one trait in each DRYLAND CEREAL crop (2014)
- Marker-assisted population improvement (MAPI) demonstrated in pearl millet (2014)

STRATEGIC OBJECTIVE 3: DEVELOPING IMPROVED DRYLAND CEREAL VARIETIES AND HYBRIDS FOR INCREASED YIELD, QUALITY AND ADAPTATION IN SMALLHOLDER FARMERS' FIELDS

Rationale and Description

While systems approaches are necessary for overcoming yield gaps over the longer term, genetic solutions – new varieties and hybrids – tend to provide low-cost entry points for more comprehensive technology changes, decreasing food shortages, and increasing levels of income (Waddington et al. 2010). Promising improved varieties or hybrids of dryland cereals will have to be adapted to the patterns of rainfall and water availability of specific target production systems. They must also be adapted to prevalent pest, weed and disease dynamics, and other constraints of specific cropping systems, such as nutrient deficiencies or toxicities, and high or low temperatures during critical growth phases. Appropriate end-use traits, such as grain and stover quality, are also essential for determining adoptability of new varieties in specific production systems. In addition to being well adapted, dryland cereals need to provide significant advantages in terms, for example, of yield potential and stability or overall commercial value to farmers. Dryland cereals traditionally have multiple end-uses: grain for food, feed or industrial uses (e.g. malting), and stover for fodder, construction, fuel, or as a soil amendment. It is this complexity and multiplicity of traits required, in view of the enormous diversity of cropping systems in which dryland cereals are grown, that is the major challenge for achieving impacts from varietal improvement of these crops. Our breeding strategies and methods have, over the past 10-15 years, evolved to become more efficient in dealing with multiple farmer-preferred traits and in targeting specific productivity improvements, as well as providing farmers with a range of varietal options for the major production systems being targeted (Rattunde et al., 1997).

The work planned under Strategic Objective 3 aims at creatively using the very wide range of genetic diversity found in these cereals, between and within species, to develop new varietal options for smallholder farmers to increase their own household food security and/or incomes via new options for marketing cereals or derived products. Products from this research will include more productive germplasm, inbred lines, varieties, and hybrids with improved yields and stability, as well as other targeted end use traits. At the same time, we will analyze and document the methods and tools used for variety development, so that learning for improved efficiency and effectiveness can occur across crops, regions and traits.

Lessons Learned

Decades of breeding research on dryland cereals have produced a number of important lessons that will guide future efforts. For example:

- Grain and fodder yield (in barley, pearl millet and sorghum) have considerable degree of independence and therefore the two can be improved simultaneously (Bidinger et al., 2009; Bluemmel et al., 2010; Goodchild et al., 1996; Grando et al., 2005; Nepolean et al., 2009,), and a significant increase in fodder quality has been achieved with just two cycles of recurrent selection. Regional variety testing can be done in a few test sites selected using available MET data to improve efficiency and cost effectiveness (Mgonja et al., 2005; 2006);
- Gains obtained while breeding for quality traits are favorable for different final uses. Selection of plump and bright grain in barley is positive for improving food, feed and malting;
- Brown midrib sorghums have higher nutritive value than ordinary sorghum, but trade-offs with biomass yield are observed in some mutants (Pinnemeni SrinivasaRao et al., 2011a/b);
- Sweet sorghums have high biomass and digestibility, hence they can be easily accepted as green fodder (Bluemmel et al., 2009);
- In sorghum, season specific selection is vital for high genetic gain from selection, both for sugars and juice in the stem, grain and biomass as well as tolerance to shoot fly;
- Significant yield gains can be achieved by applying systematic recurrent selection methods to dryland cereals (Rattunde and Witcombe, 1993; Rattunde et al., 1997);

- High diversity exists in finger millet in ESA, which could be exploited for increased productivity and for improving resistance to blast;
- The adoption of new dryland cereal varieties frequently requires improved performance under unfavorable as well as favorable conditions, and farmer participatory variety testing is essential for achieving impact (Ceccareli and Grando, 2007; Ceccarelli et al., 2007; Weltzien et al., 2008a; Weltzien et al., 2008b); and
- Participatory sorghum variety evaluations in WCA have shown that measuring grain productivity alone is not sufficient to assure increased food quantity, as grain storability and grain processing characteristics are essential criteria for adoption (Weltzien et al., 2007).

Priority Setting
The initial DRYLAND CEREALS partners have decided to focus research on one or two production systems in each region, and to implement the work in key locations having adequate research facilities and affording good opportunities to generate spillovers. Variety development efforts will be directed at creating varietal options for farmers in the context of these production systems. For each of the cereal crops and target production systems, a limited number of biotic and abiotic constraints contribute significantly to yield losses, yield instability and quality losses. The key abiotic constraints, water and nutrient availability are often confounded with socioeconomic and management-related constraints (Waddington et al., 2010). These include drought and water management, fertilizer availability and cost, soil degradation, and farmer knowledge about options for soil fertility and Striga management. The breeders' traditional focus on yield must expand to include not only grain but also the yield of stover and straw, whereby the target ratios are determined by the prevailing or predicted price ratios of grain to stover and straw for target production systems (this is information that will come from Strategic Objective 1).

In discussions among the initial DRYLAND CEREALS partners, commonalities across the four crops emerged in terms of priority traits for genetic improvement (Table 6). Improving the intake and digestibility of stover and straw was judged to be the top priority in terms of improving the overall value of dryland cereals for farmers, especially in the more drought-prone production systems, but also in those where crop-livestock integration is only just beginning. This judgment is based on: experience with variety adoption (Kelley et al., 1996); the opportunity to improve stover yield and quality at the same time as grain yield and quality; and the predicted benefits accruing to farmers in a range of production systems (Kristianson and Zerbini, 1999).

Abiotic constraints – including drought, heat, salinity and poor soil fertility – add to the rationale for working on these crops together in one program. Improving adaptation to these constraints is indispensable for improving stability of productivity, especially in view of climate change. Sharing methodologies and approaches to tackle these complex adaptive traits through exchange and collaboration across crops will provide the necessary critical mass to generate breakthroughs.

When priority traits for variety development are discussed with farmers, extension agents or breeders, the notion of "good adaptation to local conditions" invariably becomes a central focus of attention. While flowering date or behavior, and thus escape of key biotic or abiotic stresses, are key factors, other traits enter into the concept of "adaptation". This can be a predominant soil factor, such as low pH (in WCA Cereal Root Crop Mixed systems) or high pH (in the Agro-pastoral systems of SA), but also locally important pests and diseases (Table 7). The importance of such local adaptation tends to manifest itself as high genotype x environment interactions compared to the importance of genetic effects alone, when analyzing multi-location performance trials (Ceccarelli et al., 1994). In terms of priority setting for future research, such locally specific constraints will be dealt with, as necessary, as part of the efforts for productivity improvements, and will be discussed in more detail in the section describing Output 3.1 (Appendix 4). The specific priority setting for generating adoptable varieties will involve targeted actors, primarily farmers and traders or processors, in case of marketable commodities using approaches as described by Christinck et al., 2005.

Table 6. Priority traits across dryland cereals targeted for selection, in order of importance (coverage and expected impact)

Specific trait for genetic improvement	Crop and production systems where the trait is a priority
Stover/straw traits	
Intake and digestibility	Barley in Highland mixed, Rainfed Mixed, Dryland Mixed Pastoral, small-scale cereal livestock (CWANA), and Highland Temperate Mixed (ESA) Pearl millet in Rainfed Mixed and Rice-Wheat (SA) Sorghum in Cereal Root Crop Mixed (WCA) and Post rainy season and forage in Rice/Wheat systems (SA)
Abiotic stresses	
Drought-tolerance	Barley in Highland Mixed, Dryland Mixed and Rainfed Mixed, Pastoral (CWANA) and Highland Mixed (ESA) Finger millet in Maize Mixed (ESA) Pearl millet in Rainfed Mixed (SA), Pastoral (WCA) and Agropastoral (ESA) Sorghum in post-rainy season (SA)
Heat-tolerance	Barley in Rainfed Mixed, Dryland Mixed, Pastoral (CWANA) Rice-Wheat (SA), Highland Temperate Mixed (ESA) Finger millet in SA Pearl millet all farming systems (SA) Sorghum in Dryland Mixed (SA)
Adaptation to poor soil fertility, phosphorus deficiency and salinity	Barley in Rainfed Mixed, Dryland Mixed, Pastoral (CWANA) Pearl millet in Agropastoral (WCA, ESA) Sorghum in Cereal Root Crop Mixed (WCA)
Biotic stresses	
Striga spp.	Finger millet in Maize mixed (ESA) Pearl Millet in Agropastoral and Pastoral (WCA, ESA) Sorghum in Cereal Root Crop Mixed (WCA) and Maize Mixed (ESA)
Blast (*Pyricularia grisea*)	Finger millet in all farming systems (ESA, SA) Pearl millet in Rice-Wheat system (SA)
Grain quality traits	
Zn and Fe concentration and bioavailability	Barley in Rainfed Mixed, Dryland Mixed, Highland Mixed (CWANA) and Rice-Wheat (SA) Finger millet in SA Pearl Millet in Rainfed mixed in SA (contribution of CRP 4) and in Agropastoral in WCA Sorghum in all farming systems (SA), and Cereal Root Crop Mixed (WCA)
Malting quality	Barley in Rice-Wheat (SA) and Highland Temperate Mixed (ESA) Finger millet in Maize Mixed (ESA) and in SA Sorghum in Maize Mixed (ESA) and Cereal Root Crop Mixed (WCA)

Priorities for breeding research on constraints are based on the importance of yield losses, and the opportunities for using or developing new sources of resistance or combinations of resistances to achieve impact through increased yield stability. Research on yield losses (Waddington et al., 2010) and reasons for lack of adoption of improved varieties (Omanya et al., 2007; Siart, 2008) contributed to determining our breeding priorities. Monitoring production constraints with farmers during participatory research planning or evaluation sessions (van Mourik et al., 2011) have contributed, and continue to do so, to the revision of the key priorities for breeding research listed in Tables 6 and 7. Interactions with key stakeholders in India through regular Hybrid Seed Parent Consortium and All-India Coordinated project meetings drive priority setting for South Asia. For barley in CWANA, a network of practitioners (breeders, farmers and extensions workers) for participatory breeding and variety selection activities is being established, which will contribute directly to production system-specific priority setting.

Table 7. Priority traits for breeding research for dryland cereals essential for achieving impact in priority production systems

Crop	Trait	Priority production system
Abiotic Stresses		
Barley	Drought tolerance	Rainfed Mixed, Dryland Mixed, Pastoral (CWANA) and Rice-Wheat (SA)
	Salinity tolerance	Rainfed Mixed, Dryland Mixed, Pastoral (CWANA)
	Cold and or frost tolerance	Dryland Mixed and Highland Mixed (CWANA)
Sorghum	Aluminum tolerance	Cereal Root Crop Mixed (WCA)
Biotic Stresses		
Barley	Scald, net blotch, rusts, barley yellow dwarf virus	Rainfed Mixed and Dryland Mixed (CWANA) Highland Temperate Mixed (ESA)
	Stem gall midge, Russian wheat aphid	Highland Mixed, Rainfed Mixed, Dryland Mixed and Pastoral (CWANA)
Sorghum	Midge	Maize Mixed (ESA) and Cereal Root Crop Mixed (WCA)
	Grain mold	Maize Mixed (ESA) and Rainfed Mixed (SA)
	Shoot fly	Dryland Mixed and Rainfed Mixed (SA)
	Charcoal rot	Dryland Mixed and Rainfed Mixed (SA)
Pearl Millet	Head Miner	Pastoral (WCA)
	Downy mildew	All farming systems (WCA, ESA, SA)
Grain		
Barley	High (feed) & low protein (malt), High (food) & low (malt) beta glucan content, high digestibility	Highland mixed, Rainfed mixed, Dryland Mixed, Pastoral (CWANA) and Rice-Wheat (SA)
Sorghum	Low decortication losses with high Fe and Zn content	Cereal Root Crop Mixed (WCA)
	Grain luster	Post-rainy season (SA)
Finger millet	Protein and mineral content	Maize Mixed (ESA, SA)
Stover/straw		
Barley	Digestibility	All farming systems (CWANA, SA)
Sorghum	Sweet stem	All farming systems (WCA, ESA, SA)

As the cropping systems in all regions are evolving rapidly, both due to price changes, policy changes, as well as perceived climate changes, breeding priorities will need to shift, in consultation with the key actors.

The priority traits identified for each individual crop are listed in Table 7. These are traits for which research is required (identification of new sources of resistances, screening tools and breeding methodologies) to achieve significant genetic gain in the targeted production systems. There will always be other traits that are essential for achieving variety adoption, but breeding methodologies exist and are being used for monitoring and achieving progress.

Impact Pathway

The breeding research conducted under Strategic Objective 3 will contribute to three of the System Level Outcomes: Improved food security, reduced poverty and improved nutrition (Figure 7).

The contributions to the food security outcome will be achieved primarily via farmer adoption of improved varieties of dryland cereals, especially in production systems and areas within production systems that face recurrent food shortages due to abiotic or biotic constraints and inefficient production methodologies. More productive varieties that produce higher value grain, stover and straw will allow farmers to produce more food, while producing valuable by-products for sale or value addition via livestock production.

Enhanced livestock production can contribute directly to improved incomes, and thus poverty reduction, if animal products can be traded under favorable conditions. Increased livestock production can also impact further on improved crop production and profitability via enhanced availability of animal traction, and thus timelier field operations, which directly contributes to higher grain, stover and straw yields. In addition, integrated livestock production increases the availability of manure, thus improving farmers' options for soil fertility management.

Improved yields on farmers' fields will be achieved by varieties that are adapted to locally sustainable crop intensification options, as identified via Strategic Objective 4 and CRP 1.1, such as higher stand densities – especially in production systems where total rainfall rarely limits production, such as the Root Crop Cereals Mixed system of WCA. Another such adaptation will be improved Striga resistance, possibly combined with improved adaptation to poor phosphorous availability, which will express its benefits primarily in combination with other Striga management options.

Improved nutritional status, specifically of young children and their mothers, will be achieved by ensuring that young women have access to more productive varieties and hybrids. We are targeting increasing the production of dryland cereals in the fields of women farmers, where this is culturally and socially feasible, thus directly increasing grain availability for women, and possibly additional income via livestock production. Generally improved grain availability will increase food security, including for young children. This will have direct positive impacts on their nutritional status, as in general children in dryland cereal areas do not receive sufficient calories for adequate growth and development. Because dryland cereals tend to have relatively high mineral and vitamin content, and fairly high quality protein content, increasing their availability should show significant effects. Varieties with increased bioavailability of Fe and Zn will be able to contribute to the alleviation of anemia and related diseases.

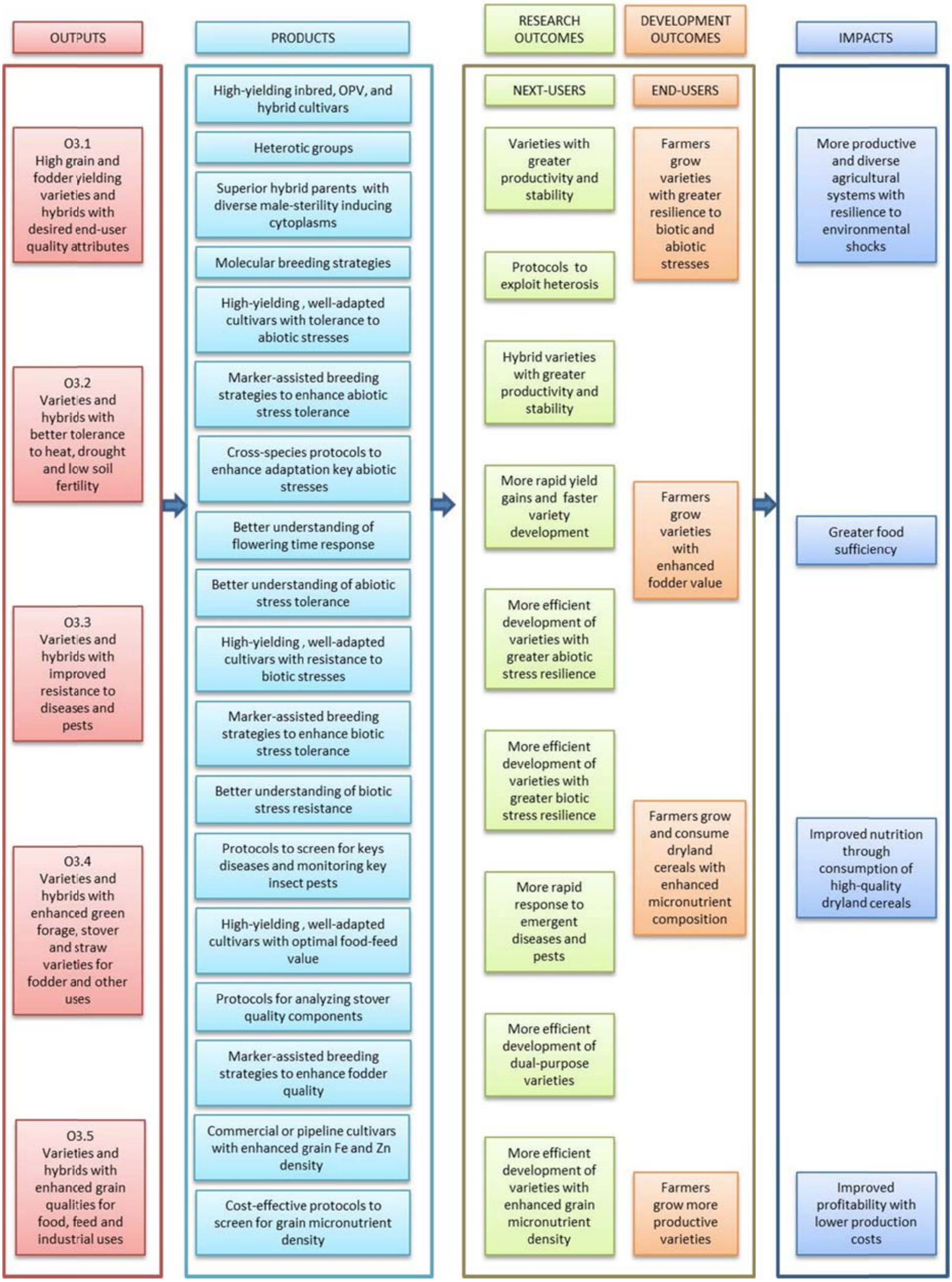

Figure 7. Strategic Objective 3 impact pathway

Key Partners

Future success from developing hybrid parents and farmer-friendly varieties and hybrids will rest on developing an array of new, non-traditional partnerships, in addition to working with established networks of partners. Local entities, such as well-established and emerging farmers' associations, will play critical roles in identifying farmers' needs and opportunities in specific zones or regions. Development organizations working to improve crop productivity and sustainability in dryland areas; private businesses that process dryland cereals for malt, beverage and starch production; and service and input providers will all be essential partners for the successful development, distribution and adoption of dryland cereals. Although coordinating efforts of these diverse actors will be challenging, several factors favor mobilization of the necessary collaboration:

- *Increased interest and commitment for dryland cereals* – Farmers' organizations and such development actors as NGOs and extension services are showing increased interest in the development of profitable dryland cereal production technologies. They are experiencing higher yields and good marketing opportunities (e.g., UGPCA with sorghum in Burkina Faso, FumaGaskya with sorghum and pearl millet in the southern part of Maradi region in Niger, and UACT with fonio (*Digitaria exilis* and *D. iburua*) and sorghum in Segou region of Mali). The fact that these cereals require lower levels of inputs and entail less risk, producing grain even without external inputs, is attracting new interest, especially in areas where the West African cotton crisis is severely reducing input availability.
- *New models for collaboration between actors are emerging* – Targeted coalitions for facilitating improved farmer incomes from dryland cereals are being developed. Examples include: professionally supported farmers' organizations that conduct multi-location trials for variety and hybrid evaluations in West Africa; women's groups demanding that more research be conducted in their own fields, under their production conditions in West Africa; NGO training of farmer facilitators and trainers for integrated *Striga* management; a consortium of malting industries contracting sorghum hybrid research in Nigeria to assure sufficient, uniform, and quality raw materials for processing; a consortium of private sector seed companies supporting hybrid parent breeding for pearl millet and sorghum in India; direct collaboration between bio-ethanol investors and sweet sorghum researchers to provide specialized hybrids and production technology; district-level agricultural offices supporting large-scale farmer managed evaluations of new sorghum hybrids and finger millet varieties for local processing industries in Tanzania; a consortium of organic cotton producers paying research support for training on new types of sorghum and pearl millet varieties and hybrids in Mali; and the FAO's World Food Program improving the capacity of farmer organizations to produce quality grain for food security stocks in West Africa.
    - Partnership with the private seed sector in India: ICRISAT's work with private sector partners has greatly contributed to the development and marketing of a very diverse range of improved hybrids and varieties of pearl millet and rainy season sorghum in Asia. For example, in India, more than 4 million hectares are occupied by over 54 rainy season sorghum hybrids developed by private sector seed companies using ICRISAT-bred parental lines or their derivatives. The ICRISAT-based private sector sorghum hybrids JKSH 22 and VJH 540, known for their high grain-yield potential, large grain, and earliness, have experienced remarkable rates of adoption and covered 210,000 hectares in 2002 and 142,000 hectares in 2003, respectively in India. Parental lines of the 15 major sorghum hybrids adapted to rainy-season conditions and marketed by the private sector in India include 9 seed parents and 10 restorer lines based either wholly or in part on ICRISAT-bred materials. All these efforts contributed to enhancing the rainy season sorghum productivity in India from a mere 695 kg/ha in 1981 to 1171 kg/ha by 2008 – an increase of 68%. The ICRISAT-Private Sector Sorghum and Pearl Millet Hybrid Parents Consortia were established in 2000 as an innovative platform for dissemination of improved research products to the farmers and to get feedback from farmers and industry for prioritizing the research on a regular basis. Furthermore, it facilitates mobilizing private sector support for public sector research.

- Promoting regional seed trade: This is a primary activity for the seed specialists employed by ICARDA and ICRISAT. During the last few years, ICARDA implemented an ECO-FAO project to strengthen the seed sector in the ten member countries of the Economic Cooperation Organization (ECO): Afghanistan, Azerbaijan, Iran, Pakistan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkey, Turkmenistan and Uzbekistan. These countries have many similarities in terms of agro-ecologies, farming systems, crops and varieties, creating a strong basis for a regional seed market that is linked to the global seed industry. Similarly, ICRISAT is engaged with regional seed system coordination efforts in WCA and ESA.
- Based on professional interaction between the ICARDA barley breeding program and the public and private brewery industries in Ethiopia and India, several superior malt barley varieties have been developed and commercialized. This has a direct impact on the livelihoods of resource-poor barley growers in those countries.
- Entrepreneurs in the field of food processing and biofuels production: ICRISAT has established through the AIP linkages with biofuel producers in India. Arrangements are also being worked out to establish links with the industry for use of sweet sorghum as feedstock in other countries like Mali, the Philippines and China. Sweet sorghum syrup is being promoted for use in drug and food industries to help farmers improve their incomes. Many dairy farmers in India and other places are showing interest in using sweet sorghum as fodder because of its higher productivity, and industries are interested in producing starch from sorghum grain.
- Multi-disciplinary research targeting specific cereal production zones: The direct collaboration between researchers from a range of disciplines from different partner institutes for solving priority challenges confronting dryland cereal producers will be at the heart of this research. The key to engagement is to focus on the common goal of enhancing cereal farmers' livelihoods, and to put mechanisms in place to ensure that activities are demand driven. Research partnerships with universities and advanced research institutes for specific technical, social and institutional issues are essential for the success of this program.
- Regional cooperation within the same agro-ecological zones: Exchanging germplasm, concomitant diversification of national breeding materials (to increase heterozygosity and therefore hybrid vigor in the hybrids), and joint multi-location hybrid evaluation trials within similar agro-ecological zones across countries can enhance hybrid breeding efficiency in SSA, through the "Lead NARS" approach of regionalized breeding for increased efficiency and cost effectiveness (Mgonja et al., 2005,2006, 2008). This approach will characterize DRYLAND CEREALS, with support from sub-regional organizations (e.g., CORAF, ASARECA, SADC, and others). Mechanisms for regionally harmonized cultivar registration, seed certification, and quality control, as well as Sanitary and Phytosanitary Standards, will facilitate farmers' fast access to new improved cultivars.

Gender Strategy

Strategic Objective 3 will assess the "whole plant value" as it pertains to entire farm family, especially in situations where the crop serves as the staple food for much of the year, and family labor is the key source of labor for cultivation and processing. Achieving balanced criteria for evaluating, creating and disseminating new varieties of dryland cereals requires:

- Improvements in the gender knowledge and analysis skills of the scientists and other partners involved;
- Commitment of partners along the research continuum to act on gender-specific client needs, and develop technology options with benefits to the whole farm family;
- Commitment of research and development partners to communicate successes and failures of specific actions in this direction; and

- Effective increases in whole plant value or productivity of the dryland cereals.

To facilitate these changes, the cereal improvement teams in the different regions are committed to:

- Including woman farmers as members of project steering committees;
- Assessing the roles of women in various crop management and processing operations in targeted regions;
- Supporting women self-help groups in target regions, especially in the context of cereal processing and commercialization;
- Inclusion of women in decision making, especially regarding the choice of varieties;
- Establishing specific variety trials for women, adapted to enable their direct participation;
- Communication and training targeted specifically for women and women's associations, avoiding the pitfalls of indirect communication through husbands and giving less attention to the specific needs of women;
- Feedback sessions, discussing results of experimentation specifically for and with women;
- Training women farmer groups to adopt affordable mechanization to reduce drudgery and labor in agricultural operations, and to develop their enterprise skills; and
- Making information on nutritional advantages and innovations readily available to all members of the household.

Innovations
Strategic Objective 3 will make use of a number of innovations in plant breeding and related fields to improve the efficiency and effectiveness with which new varieties and hybrids are produced. These include:

- Use of male-sterile lines to ease the tedious crossing process in finger millet breeding. The small size of the plant's flowers, and the plant's selfing nature, makes crossing very difficult. Using a sterile male line will make crossing easier and more efficient;
- Stratification of test sites and breeding for specific adaptation by targeting recommendation domains in each region across country boundaries for all crops and major production systems. Crop breeders will make the necessary efforts to better match the food/feed traits of new cultivars to the needs of smallholder farmers in different agro-ecological systems. This will be achieved by characterizing domains by cropping areas, population densities, livestock populations and productivity, and feed resources, which in turn will enable better targeting of breeding efforts to the needs of farmers in different agro-ecological zones (this work will be done jointly with Strategic Objective 1).
- Exploiting heterosis by identifying heterotic groups to bring benefits of sustainable hybrid vigor to SSA;
- Integrated improvement for food and fodder and for whole plant utilization to increase the value of production, types of products, and market opportunities for specific target systems;
- Identifying germplasm with specific adaptation to low soil phosphorus (P) conditions, and developing breeding strategies to effectively incorporate this adaptive trait;
- Farmers, both women and men, will be involved in the selection of hybrid parents derived from populations representing complimentary heterotic groups. They will evaluate new hybrids and identify new traits to target. These hybrids will be easy to produce using stable female parents and male parents that produce well, and will meet grain quality criteria for home consumption, including high micronutrient densities;
- Hybrids will be bred to produce higher and more stable yields in extreme stress environments, producing more when it is needed most. Examples include: pearl millet in the rainfed areas of India and the Sahel in WCA; barley for vast expanses of the steppe; sorghum

for residual moisture conditions in southern India, photoperiod sensitive sorghums adapted to low phosphorus conditions in WCA, and similar disadvantaged regions of dryland cereal production.

- Modern tools – molecular, quantitative and participatory – will be applied to draw on local and regional crop diversity. Traits for adaptation will be better understood, germplasm better characterized and differentiated into heterotic groupings, and genetic markers and other tools will be used to improve specific traits, such as downy mildew resistance in pearl millet, *Striga* resistance in sorghum, and abiotic stress tolerance in barley. These modern tools will allow the maintenance and increase of local biodiversity, with significant increases in productivity and stability of production;
- Double haploids coupled with molecular markers will be employed to accelerate the efficiency of variety and population development;
- Hybrids will be developed for specific uses: sweet sorghum for juice extraction; sorghum and barley for malting industries; and pearl millet for green fodder production under extreme heat conditions. As processing options achieve larger markets, hybrids can be identified with specific endosperm characteristics, micronutrient composition, or stem composition. The diversity of quality characteristics offered by the dryland cereals needs to be unlocked to create new market opportunities for smallholder farmers;
- Farmer-driven and market oriented trait breeding will be done. For example, post rainy season sorghum grain fetches higher grain prices (about 100-250% more) than rainy season sorghum in SA. Malting barley commands a 20-25% premium in Ethiopia. Considering the grain quality attributes that fetch higher prices and incomes for farmers, ICRISAT is proposing to allocate more resources in improving sorghum for post-rainy season adaptation.
- Nutrition concerns will be addressed along with targeted productivity increases. In most DRYLAND CEREALS production systems, malnutrition, especially among young children and their mothers, is dramatic. Through the work on Fe and Zn concentration, biofortification and bioavailability, as well as the gender-focused approach for variety testing, we expect that pathways will be identified for improving productivity and access to better quality grain for women and their children.

Capacity Building, Knowledge Sharing and Communication

Plant breeding and variety development – Generally, capacity for plant breeding and variety development is actually becoming rare, as applied genetics research and teaching in universities and other ARIs has moved towards molecular genetics research. Molecular research tools have advanced so rapidly that they now present fundamentally new opportunities for making variety development, in all its complexities, a more efficient and effective process. Skills and capacities to harness these opportunities for the dryland cereals need to be nurtured, so that these tools and methods become an integral part of doing business to achieve the targeted outputs of this strategic objective. This will include: training on quantitative genetic principals for analyzing options for improving genetic gain; new statistical tools, especially to exploit performance and phenotyping data; and database management and utilization. Without a concerted effort on this type of training, the capacity to achieve genetic gains in dryland cereals will rapidly decline, as many experienced NARES and CGIAR scientists are close to retirement. The CRP will support AGRA's efforts by hosting and advising students, and contributing to specific training courses. We are generally maximizing efforts to train graduate students, especially in collaboration with universities with good training capacity for molecular breeding. The centers' and NARES contributions tend to focus on providing training in managing efficient field trials, and phenotyping experimentation, as well as insights into multi-stakeholder-driven priority setting for appropriately targeting breeding research to clients' demands. In addition to training a new generation of breeders, it is important to ensure that NARES and center breeders upgrade their skills, and learn to better harness the opportunities presented by the new tools. Care will be taken to interest young women in these areas of research.

Data management, sharing and exchange – With DNA sequencing and genetic marker analysis becoming easily accessible, the amount of data and information on specific genotypes will increase exponentially. In turn the demand for field performance data, plant analysis data, farmer preference data, as well as data from specific trait analyses will be highly sought after. Thus, publicly funded longer-term field research will become increasingly important resources, if well managed and documented. The skills for doing this effectively will be developed by upgrading the centers and partners' software for these tasks, and systematically training scientific and technical personnel and partners in their effective use. As ICT advances, virtual sharing of data sets and joint analyses with partners located in different sites will become a reality for partners in this research program.

Communicating research results – Achieving outcomes and impacts from DRYLAND CEREALS research hinges on effectively communicating results to target audiences. This is especially true for the lesser-known crops targeted by this CRP. Training researchers to publish findings for peer audiences will be enhanced in order to ensure that knowledge about "climate change ready" dryland cereal crops is readily accessible. However, scientific publications are not enough. The creation of new varieties of dryland cereals is of immediate importance to a wide range of actors in the seed value chain. To create demand for improved seed, farmers will need clear information about specific varieties, seed availability and marketing options. Development actors will require information about possible benefits from the use of new technologies. Researchers and technical personnel will be trained to use a wide range of media and harness new ICT options. This will help to overcome one key constraint to adoption, mentioned by farmers in many adoption studies: "lack of information" (Omanya et al., 2007; Yapi et al., 2000).

Facilitating variety adoption and seed delivery – Applied research in variety development justifies itself by the benefits it creates for those who adopt these varieties. Improvements, i.e., changes of individual traits alone, rarely lead to wide-scale adoption, unless everything else is "just right". Breeders and others involved in variety development thus require skills to orient their efforts towards understanding and meeting clients' needs. This may be as straightforward as understanding market demands, and requiring the skill to interact with industrial processors to understand their concerns. If variety adoption is to support food-insecure farm families in overcoming recurrent food shortages, careful identification of key bottlenecks for increasing production in the specific socioeconomic and biophysical environment is essential. Interdisciplinary diagnostics skills, including gender sensitivity and knowledge, largely hinging on effective communication and facilitation skills but also on production systems thinking are essential to ensure that effective partnerships between producers and breeders can develop.

Seed systems innovations serving the needs of underprivileged dryland farmers, men and women, must ensure that aspects of seed security, even under severely adverse conditions are taking into account. This is particularly important when preparing for the adverse effects of climate change, which is predicted to increase climate variability, unpredictability, and thus production risks for farmers. Teams involved in variety development tend to require training in such systems analysis. These skills also enhance the teams' chances to collaborate successfully with development partners, which is essential for facilitating production changes.

Types of training – Training for advanced academic degrees is at the heart of much of the above capacity building effort. We expect that in the next few years, distance learning opportunities for advanced degrees will improve, and will make such degrees more accessible to students from our target regions, where advanced training options tend to be limited. This will also facilitate students conducting supervised field experimentation related to these degrees in their own target environments, and thus increase the chances that new skills will create innovations in the target region itself.

Short courses will be the other pillar for this training plan. Communication and social science-related skills will require close interaction with trainers, as the student benefits from immediate feedback when trying out new skills in a training setting. Similarly, data analysis and management relative to specific breeding methodologies lends itself to short courses. It tends to be most useful if the training course is linked to some immediate action plan or project activity, so that learning is hands-on, with possibly monitoring and feedback from the trainer. As more and more partners have access to the Internet, we expect this type of training and mentoring being done long-distance.

Finally, fellowships that allow researchers from partner institutes and countries to spend extended periods at one of the DRYLAND CEREALS research centers will allow for practical hands-on training, monitoring for the acquisition of specific methodological skills and knowledge, and for carrying the research through to a communicated result.

Outputs and Milestones for Strategic Objective 3 (further details are in Appendix 4)
3.1 High grain and fodder yielding varieties and hybrids with desired end-user quality attributes

Dryland cereals are primarily staple crops, and thus the quantity produced, especially in poor years is an essential criterion for variety adoption. Breeding varieties with higher and better quality grain, stover or straw, i.e., a focus on "whole plant value productivity" is the overriding goal for dryland cereal breeding programs. Fortunately, large genetic variability exists for a range of traits in dryland cereal germplasm collections and breeding materials, and effective breeding methodologies are available to substantially improve the quantity and quality of grain and crop residues.

Milestones

- At least 10 superior hybrid parents for diversification of for hybrid breeding options for sorghum and pearl millet in SA and starting hybrid breeding in WCA identified (2012)
- At least 2 new finger millet, sorghum and barley varieties identified for promotion in at least 2 target production systems (2012)
- Pearl Millet and Sorghum populations initiated for recurrent selection for adaptation to at least 2 specific new target conditions (2013)
- Analysis of genetic diversity patterns of prior studies combined with new studies for improved identification of heterotic groups for breeding hybrid parents of sorghum and pearl millet (2013)
- Methods tested for improving efficiency of crossing in finger millet (2013)
- Superior sorghum parents for total biomass yield and specific quality trait identified (2014)
- Populations of barley developed with increased out-crossing rate using recurrent selection, and morphological as well as biochemical markers (2014)
- Efficiency of recurrent selection schemes for sorghum and pearl millet for target production systems with high variability and poor predictability of abiotic constraints assessed (2014)
- At least 200 genetically diverse, high-yielding and locally well adapted early-generation restorer progenies of A4 and A5 CMS systems developed in pearl millet and female and male parents for A1, A2 and A4 CMS systems for sorghum for at least two target production systems (2014)

3.2 Varieties and hybrids with better tolerance to heat, drought, salinity and low soil fertility

Dryland cereals, by definition, are well adapted to drought and heat stress during key stages of crop development, and can produce grain and straw/stover when other crops fail. They are also remarkably resilient under poor soil fertility conditions. However improved adaptation to drought, heat, salinity and limited soil fertility is necessary for improved yield stability over time, and to reduce the predicted negative effects on food security and the incomes of dryland farmers in the face of climate change.

Milestones

- QTLs identified for traits related to drought tolerance for at least 2 species (2012)

- Analyses of genotype by environment interactions of variety performance trials of dryland cereals linked to water availability estimates for specific production systems and zones for at least two dryland cereals (2012)
- Protocol for drought tolerance screening developed for finger millet in ESA (2012)
- At least 10 parental lines of pearl millet, sorghum, finger millet and barley adapted to arid conditions developed (2013)
- Core set of genetic stocks representing effective sources of drought, heat-adaptation and salinity tolerance traits assembled in barley, pearl millet and sorghum (2013)
- Stability of at least one specific drought tolerance trait assessed in a range of target genotypes in naturally drought-prone environments, for at least two species (2014)
- Markers identified for genomic regions conferring P efficiency in sorghum (2014)
- Salinity tolerant varieties of sorghum and barley (3) and hybrids of sorghum (2) with high biomass and grain yield in at least two target production systems developed (2014)

3.3 Varieties and hybrids with improved resistance to diseases and pests

Insect pests and diseases of dryland cereals have very specific and evolving distribution patterns, which are likely to change with the intensification of certain production systems and with climate change. Varietal resistance is the best option for reducing losses due to biotic constraints, often in conjunction with crop management measures that entail more sustainable IPM options (see Strategic Objective 4).

Milestones

- Sources of resistance to fungal leaf and root diseases identified in both cultivated and wild barley (*H*. *vulgare* subsp. *Spontaneum* and *H*. *bulbosum*), including parents of existing mapping populations, as well as for finger millet (blast and Striga) assembled and multiplied (2012)
- Screening protocols refined to identify sources of resistance or tolerance to specific pests and diseases (head miner in pearl millet; midge on sorghum, aphids on sorghum and barley), diseases (blast in pearl millet and finger millet; grain molds in sorghum, net blotch, mildew, scald, and BYDV and Wheat stem sawfly and barley gall midge in barley in CWANA, rust in SA and ESA (2012)
- Elite composites of pearl millet with combined resistance to downy mildew and blast developed (2012)
- Hybrid parental lines or varieties with resistance to downy mildew in pearl millet (WCA, SA), blast in pearl (SA) and finger millet (ESA, SA); *Striga* on sorghum in WCA, foliar diseases and grain mold in sorghum and barley; and shoot fly, stem borer, and aphid in sorghum, and aphid in barley identified and distributed to NARS (2013)
- Off-season downy mildew screening facilities for pearl millet installed in at least one country in WCA (2013)
- Genetic diversity of *Striga hermonthica* samples from WCA assessed using molecular markers (2013)
- Evolution of virulent strains of downy mildew in pearl millet, blast in finger and pearl millet, and net blotch, powdery mildew, scald and rust in barley monitored, and the information shared with NARS (2014)
- Marker assisted transfer of specific resistance/tolerance alleles into farmer preferred varieties documented (Downy mildew on pearl millet, *Striga* and shot fly on sorghum, foliar diseases for barley) (2014)
- QTLs or allele markers identified for the transfer of specific resistances/tolerances into target genotypes (*Striga* on pearl millet, aphids on sorghum, foliar diseases of barley) (2014)

3.4 Varieties and hybrids with enhanced green forage, stover and straw varieties for fodder and other uses

The increasing demand for livestock products along with decreasing availability of arable land and water will not only increase the demand for green forage, but especially for dry stover and straw. We will bring about a paradigm shift in dryland-cereal variety development to breed concomitantly for superior grain and green forage/stover/straw traits, to maximize total plant value for dryland cereal farmers.

Milestones

- Review of options for improving total plant value of dryland cereals conducted by CRP partners, across crops and production systems (2012)
- Experimental varieties of sorghum, pearl millet and barley characterized for components of total plant value for specific production system scenarios (2012)
- NIRS protocols transferred to all target regions, and available for breeding programs for analyzing straw/stover quality components (2013)
- Sweet sorghum germplasm accessions (3) for multicut trait identified in SA from the global collection (2013)
- High biomass sweet sorghum lines (3) introgressed (to BC2) with low lignin *bmr* genes (2014)
- Dual purpose varieties identified for at least 2 dryland cereals in different target production systems combining superior grain yield with increased straw/stover value (2014)
- Marker assisted selection successfully applied to increase quality and value combined of stover and grain beyond released cultivars for at least one dryland cereal (2014)

3.5 Varieties and hybrids with enhanced grain qualities for food, feed and industrial uses

Grain quality includes traits that are readily visible (size, shape, color, texture, storability of the grain) and are of direct immediate value to farmers and consumers. These will continue to be an integral part of genetic enhancement of all the dryland cereals. However, many quality traits of considerable nutritional and industrial significance are invisible. These invisible traits – such as nutritional content and industrial and processing quality – will be prominent on the crop improvement agenda.

Milestones

- Rapid and cost-effective screening protocols for mineral analysis in grain (Fe, Zn and Ca) of sorghum and millets standardized (2012)
- Finger millet grain profiled for key nutrients and minerals, based on a range of cultivars and advanced breeding lines from ESA and SA (2012)
- Decortication losses of a range of sorghum and pearl millet cultivars quantified, also for the consequences for Fe and Zn concentration, and indications for their bioavailability (2013).
- Source materials with high mineral content identified among advanced breeding lines, and commercial/pipeline hybrids/varieties of sorghum (Pearl millet in CRP 4) (2013)
- Commercial and pipeline cultivars of pearl millet and barley characterized (at least 40 in each crop) for poultry and small ruminant feed quality traits, including anti-nutritional factors (2013)
- Screening protocols for screening barley germplasm for malting quality (2013)
- Commercial and pipeline cultivars (at least 40 in each crop) characterized for processing and value-addition related nutritional traits, and starch and bio -active compounds (2014)

Strategic Objective 4: Developing sustainable crop, pest and disease management options to capture genetic gains from improved dryland cereal varieties and hybrids

Rationale and Description

Strategic Objective 4 will target affordable crop management options that contribute directly to increased dryland cereal yield and quality and meet the requirements of smallholder farmers in Africa and Asia. These options, including nutrient application, seed priming, and integrated management strategies for biotic and abiotic constraints (IPM/IDM), will exploit genetic gains achieved in Strategic Objective 3 and help close the gap between on-station and on-farm yields. Additionally, Strategic Objective 4 will feed information back to researchers on traits and plant types needed for low soil fertility, variable rainfall conditions and different farming systems. Many of these crop management activities will be carried out in conjunction with CRP 1.1 to ensure that interventions are designed using existing knowledge and experience of farming and livelihood systems.

The integration of crop management practices and varieties to overcome biotic and abiotic constraints will be validated and improved through an assessment of current on-farm practices and using farmer participatory experimentation and testing. Given the complexity and dynamism of dryland cereal farming systems, one of the prime objectives will be to improve the adaptive capacity of the system and that for the farmers, i.e., the ability to sustain a flow of diverse products and services that poor people depend upon, and to do so under constantly changing conditions. Research will need to strengthen farmers' ability to manage a broad range of production factors, thus increasing her flexibility to respond to exogenous influences. Ultimately, the synergy between cultivar development and crop management research must involve farmer participation and farmer decision-making processes. Strategic Objective 4 also aims at integrating crop management with improved cultivars to address key biotic and abiotic stresses. Strategic Objective 4 will develop and use decision-support systems for farmers to work towards more productive, less vulnerable, and more resilient dryland cereal system.

Over the years, researchers have developed improved genotypes, tillage/soil management systems, and integrated pest/disease management packages. Intensification of dryland cereal rainfed agriculture requires greater use of inputs and investments on these inputs and will often involve a higher level of production risk. It is unlikely that impoverished risk-averse smallholder farmers will be willing to make such investments without assurances of a high probability of success and good rates of return to their investments. In this context, prudent management of available water is critical to reduce production risks, especially in water stressed areas. This is further exacerbated by the prediction that in many parts of SSA, available water resources are going to shrink due to changes in climate. Current projections indicate that Ethiopia, Kenya, Rwanda and Burundi will experience serious water scarcities by 2025. Efforts must therefore be made to capture and more effectively use water that is already available.

The relative importance of abiotic constraints in determining yield gaps has not been well defined for dryland cereals, though in general soil fertility and water management are the key to improving production of grain and stover. Many studies have shown that the application of nutrients in small quantities, both macro (NPK) and micro (boron, zinc, etc.) can substantially raise cereal yields and increase crop water use efficiency. When these interventions are combined with other aspects of crop management, such as specific tillage practices, e.g., zero tillage, contour ridging, in-field water harvesting, and rotation with legumes, then productivity can be further enhanced (Subbarao et al., 2000; Zougmore et al., 2010). *Ex-ante* simulation studies have clearly shown that even with existing cultivars, improved management practices can raise yields and reduce risk in variable climates (Cooper et al. 2009).

Among the biotic stresses affecting dryland cereals (except for barley), *Striga* is the most damaging obligate parasite, affecting a wide range of hosts (sorghum, pearl millet, finger millet, rice and maize). *Striga* is a serious constraint to production, productivity, and utilization of dryland cereals. Crop losses due to this pest have been estimated at over US$ 7.4 billion annually (Sharma 2006). Over 50% of sorghum production fields in Ethiopia are infested by different *Striga* species. Average yield losses due to *Striga* infestation in Africa ranges from 40-100%. Parasitism develops through exchange of complex biochemical signals, in which strigol initiates or stimulates the germination of *Striga* and its attachment to the root of the sorghum plant or seedling. Common weed control methods are usually ineffective, because the parasite emerges after the normal weeding or herbicide use period. Damage is more serious in areas where soil fertility is already low and drought is prominent.

Integrated *Striga* management packages have been designed that include: *Striga* resistant varieties; judicious and appropriate timing and application of phosphate, nitrogen and composite fertilizers in combination with organic fertilizers; and water conservation measures using tied ridges (or local alternatives). *Striga* management will continue to require cultural and chemical treatments, resistant varieties, and an integrated approach to both *Striga* and soil fertility. Of these approaches, development of resistant crop cultivars has been recognized as the most effective and feasible method. To date *Striga*-resistant sorghum cultivars – such as N13, SRN39, Framida, 555, ICSVs, SRN39 derivatives (P401 to P409), Soumalemba (IS15401), Seguetana CZ and CMDT45 – have been identified and, as has been observed by Tabo et al. (2006) and ICRISAT (2009), these can be integrated with available crop management options to enhance productivity.

Weed management is the primary bottleneck to yield increases by smallholder farmers, yet has been neglected by researchers in recent years on the premise that this is a straightforward crop husbandry practice in which farmers should invest. However, because of labor shortages most farmers prefer to use herbicides for controlling weeds other than *Striga*. As patents for key herbicides (such as glyphosate and atrazine) and others expire, their availability and use in dryland cereal production areas is increasing, in many areas without technical guidance or understanding of the potential health risks involved. Research support is thus needed to guide safe and efficient use, and to develop alternative options for diverse dryland cereal production environments.

A number of important pests and diseases of dryland cereals have very specific and evolving distribution patterns. Grain molds, shoot fly, stem borers, midge, and head bugs are important pests in sorghum across the SSA and SA regions whereas downy mildew, blast, stem borer and head miner are important in pearl millet. Finger millet blast (Mgonja et al., 2007) and stem borers are important in SA and ESA and elsewhere where finger millet is produced. The productivity of barley is constrained by globally important foliar diseases, such as scald (*Rhynchosporiumsecalis*), net blotch (*Pyrenophorateres*), leaf rust (*Puccinia hordei*), powdery mildew (*Erysiphe graminis* f. sp. *hordei*) and barley yellow dwarf virus. Crown and dryland root rot diseases caused by *Fusarium* spp. (*F. graminearum* and *F. culmorum*) are also important diseases of barley and wheat in the Maghreb countries. Aphids are important barley insect pests in CWANA and ESA. The Russian wheat aphid (RWA), *Diuraphisnoxia* (Kurdjumov), and the Barley stem gall midge (*Mayetiola hordei* Keiffer) are the most important insect pests of barley in CWANA. RWA losses of up to 60% have been reported in countries such as Ethiopia and Turkey, especially in dry years. The Barley stem gall midge has been the major pest of barley in North Africa (Morocco, Algeria, Tunisia and Libya) causing about 30% yield losses (Lhaloui et al. 1992). Recently, and as result of climate change, this pest has also become an important pest of barley in Syria

Lessons Learned

Several important dryland crop management-related lessons have been learned over the years:

- Crop and natural resource management practices that improve soil fertility, production and profitability do exist; however, farmer adoption of improved crop management practices on dryland cereals and especially sorghum and millets has been low (Hagmann et al., 2002; Ley et al., 2001) for various reasons. This is especially true of soil fertility (both organic and inorganic fertilizers) and soil water management practices.

- Farmers are reluctant to invest in new crop management practices for two reasons: high production risks where dryland cereals are produced and limited incentives to increase productivity, largely due to limited access to markets for these small grains. A host of other issues, such as unavailability of inputs, lack of awareness or information about improved practices, or inappropriate recommendations for dry areas has also played a role. However on the other hand, farmers will find ways to adopt/adapt new NRM and crop management technologies into their farming systems when incentives are sufficiently high from their perspective and the technology adaption and adoption process is adequately supported and explained (Twomlow et al., 2006; Van Mourik, 2008).
- Crop management practices, including IPM, IDM and ICM (integrated pest, disease and crop management, respectively) are more knowledge intensive than seed technology, and require different approaches that are often location specific and local in nature (Pound et al., 2004). Participatory approaches based on diagnosis, validation, experimentation and demonstration with farmers, and popularization have proved successful and include such approaches as the *Striga* and soil fertility cluster-based farmer field school approach (CBFFS; see http://hope.icrisat.org/manual-for-implementing-cluster-based-farmer-field-schools-for-integrated-*Striga*-and-soil-fertility-management/). Once a farming system or region specific IPM, IDM or ICM practice has been developed, tested and validated, the challenge is finding ways to scale up these approaches.
- The approaches used for *Striga* and soil fertility have shown some early encouraging results, not only scientifically but also in terms of farmer knowledge exchange and adoption. CBFFS is being adopted by national research partners and NGOs that see the resource and time-scale benefits of the approach. Strategic Objective 4 will use the CBFFS approach for the most important constraints to the production of dryland cereals in new areas to develop, adapt, test, and scale up integrated management approaches.
- Another key lesson for crop management and related technologies is the need to link these interventions to other actions that address bottlenecks in the impact pathway. Fertilizer use in SSA is dismally low, less than 10 kg/ha on average, and simply advocating fertilizer use without addressing issues of supply and marketing of surplus product will change nothing. Microdosing, for example, arose out of the recognition that small quantities of fertilizer could make a significant difference to yields, were more likely to be affordable than the recommended rates, and were relatively risk-free (Tabo et al., 2006; Twomlow et al., 2006). Linking microdosing to credit and storage schemes (“warrantage”) ensures that farmers can both afford and obtain fertilizer, and can subsequently store the crop to obtain a higher price, leading to greater and more sustainable adoption of microdosing. Likewise, in Zimbabwe the promotion of conservation agriculture is enabled by free seed and/or fertilizer under protracted drought relief schemes.
- Specific to pests and diseases, key lessons include:
    - Pesticide application is not feasible for the control of panicle feeding pests;
    - Host plant resistance is not adequate to control many insect pests and diseases, e.g., sorghum shoot fly, stem borer, grain mold and head bugs in sorghum, and blast in finger millet;
    - There is evidence of development of resistance to metalaxyl in downy mildew pathogen in sorghum; and
    - Pesticide application is not only uneconomic, but also unavailable in most parts of Africa, and hence needs to be combined with moderate to high levels of host resistance to target pests.

Priority setting

Finger millet, pearl millet and sorghum in ESA – The Eastern and Central Africa Regional Sorghum and Millet Network (ECARSAM), established by ASARECA in 2003, conducted a regional priority setting exercise in 2003 and 2004. A step-wise priority setting process, using the "analyze-formulate-evaluate" sequence, was followed to identify the priority issues for sorghum and millet research. Participants in the priority setting were drawn from the private sector (e.g., food processing, seed producers, breweries), research institutions, universities, NGOs, and farmers' and donor organizations. The balancing composition of the stakeholders from different sectors (production, processing marketing, policy, etc.) was essential to address the entire value chain and to overcome biases towards self-interest in prioritization of research themes.

The outcome of the process indicated the following priorities:

- Development, dissemination and promotion of integrated water management practices for increased productivity and livelihoods in drought stressed areas;
- Participatory development, dissemination and promotion of high yielding sorghum varieties for specific end-use for different agro ecologies;
- Participatory development, dissemination and promotion of high yielding millet varieties for specific end-use for different agro ecologies; and
- Participatory development, dissemination and promotion of integrated Striga management option.

Table 8. Crop management technologies for dryland cereals

Technology	Description
Water/moisture conservation	
Tied ridges	Tied ridging is a type of surface configuration whereby the ridges are "tied" to each other at regular intervals by cross-dams, blocking the furrow and can be used when surface run-off is to be prevented.
Pitting	Pitting techniques, where shallow planting holes (< 35 cm deep) are dug for concentration of surface runoff and crop residue/manure. Found to be very effective especially in drier locations.
Trash lines	Trash lines are constructed as a barrier for runoff, and soil erosion using maize, sorghum and teff straw/stalk
Conservation Agriculture	Conservation tillage was developed to protect the soils from sealing rainfall, to achieve and maintain an open internal soil structure, to enhance biological processes in the soil, and to develop a means for safe disposal of any surface runoff that nevertheless will occur.
Pest and disease management	
IPM/IDM	IPM is a sustainable approach to managing pests by combining host plant resistance, biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks

Technology	Description
Soil and crop management	
Microdosing	Precision application of small amounts of fertilizer next to the emerged plant, from three to six weeks after the plant has emerged after weeding, and when there is adequate soil moisture. The rates, types and fertilizer application methods vary by location, and are determined through the use of crop simulation modeling and field validation.
Seed priming	Giving crops a good start where good crop establishment is often the problem by minimizing the time required for seed germination and seedling emergence by soaking seeds in water before sowing

In the SADC region, at the closure of the Sorghum and Millet Improvement Program (SMIP), stakeholders agreed that “improved crop management is the key to greater productivity and food security”. Crop management technology options for smallholder farmers have been developed, tested and piloted, although they remain to be mainstreamed and disseminated to national extension agents (Heinrich, 2004).

Strategic Objective 4 is focusing its activities on priority farming systems as well as areas with potential for sustainable production and productivity increases. Since there is a range of crop management options to be considered and integrated (Table 8), decisions will also be informed by interactions with sub-regional organizations.

Sorghum and pearl millet in WCA – Over all farming systems present in WCA, soil fertility is the most important abiotic constraint (Breman, 1995) while *Striga hermonthica* is the most important biotic constraint (Gressel et al., 2004). Soils in the semi-arid regions of WCA are especially poor in nitrogen and phosphorus, which constrains growth of dryland cereals more than the limited rainfall and poor soil moisture (Breman, 1995). Micronutrients such as zinc and boron may also be limiting in specific areas, requiring a proper assessment of soil fertility and specific soil nutrient management strategies. Recently, fertilizers coating macronutrients as well as micronutrients have appeared on the fertilizer market and experimentation should be geared at assessing the relative (economic) efficacy of these fertilizers in relation to macronutrient fertilizers and organic fertilizers. Other important biotic stresses for the DCs in WCA are weeds, diseases (downy mildew, smut) and insect pests (head miner, stem borer, midge and head bugs). In WCA, weeds are a very important constraint in the cereal-root crop-mixed and maize-mixed farming systems. In response to limited labor and mechanization, farmers are turning more and more towards the use of herbicides for weed control. This change in farmer behavior needs to be accompanied by participatory research and agronomic trials, as well as appropriate knowledge and extension to help farmers achieve the best results with herbicides, while at the same time minimize environmental and health risks. Downy mildew is the most important disease for pearl millet, and existing technologies such as seed treatment products and resistant varieties need to be combined and integrated with other practices to achieve IDM. Also important for pearl millet, but much more variable and epidemic in occurrence in time and space is millet head miner. Control options for millet head miner also exist (biological control and varietal tolerance/resistance) and need to be used in combination and undergo site-specific fine-tuning.

Sorghum and pearl millet in SA – Research on yield losses (Waddington et al., 2010) and the reasons for lack of adoption of improved varieties (Omanya et al., 2007; Siart, 2008) contribute to the identification of priorities. Monitoring production constraints with farmers during participatory research planning or evaluation sessions (van Mourik et al., 2011) have and continue to contribute to the revision of the key priorities. Interactions with key stakeholders in India through regular hybrid seed parent consortium and All-India Coordinated project meetings mainly drive this priority setting process. ICRISAT is focused on harsher environments in South Asia, where yields are low and there are large numbers of smallholders. The constraints for sorghum production in SA include:

abiotic stresses, such as drought and moisture stress due to weed competition (32.5%), biotic stresses (12.5%), and unavailability of quality seed (10%) under rainfed mixed farming systems; they account 38%, 22% and 8%, respectively, under dry rainfed systems. In the rainy season, shoot fly grain mold and anthracnose are important and in the post-rainy season, temperature sensitivity, shoot fly, terminal drought stress, and charcoal rot are important. Thus, Strategic Objective 4 activities will largely be focused on research that will benefit the large post-rainy season sorghum area in SA. For pearl millet, important abiotic stresses are drought and high temperature. Downy mildew continues to be major biotic stress to pearl millet production that requires utmost attention followed by blast that has emerged serious problem in the recent past.

Barley in CWANA – The CWANA region suffers from a shortage of food and is a major importer of strategic food commodities. Productivity growth is declining and there is potential for increased food prices. To address the present and foreseeable challenges to food security, the region has conducted various priority-setting activities for agriculture research and development. In 2002, ICARDA, in close collaboration with AARINENA and CAC forums, launched a region-wide initiative aimed at revisiting and refocusing CWANA research priorities through an innovative consultation mechanism relying on a bottom-up approach and broader participation of non-traditional stakeholders (Belaid et al., 2003). The research prioritization identified five researchable issues in the region in 2002. The first one was germplasm management, including germplasm improvement and biotechnology, genetic resources conservation, integrated pest management, and seed production. The second key issue was production and productivity of crops (wheat and barley, forages, vegetables, industrial crops, legumes, fruit trees, maize, potato) and forests. Shideed et al. (2008) reported the methodology used during brainstorming sessions, questionnaires, and regional as well as national consultations. The outcome indicated that the drylands were the most important agro-ecology (ranked first), followed by rangelands. On germplasm management, IPM was rated second after germplasm improvement and biotechnology. On germplasm, wheat and barley were highly rated (rated first) and on NRM, water and soils were ranked first.

The latest priority setting initiative was done in preparation for the March 2010 conference on setting a regional research agenda (Samir El-Habbab et al., 2009). The purpose was to lay the foundation of a regional partnership that would facilitate consensus on the identification of common agricultural research priorities to be addressed within a regional framework, which would enhance synergies, efficiency, and impact. The basic premise being that such a regional process would strengthen partnerships among and between NARES and create opportunities for a more effective division of labor and more efficient use of other resources that would greatly enhance the likelihood of impact. Clearly, the effectiveness of regional research initiatives would greatly depend on the facility with which consensus on common problems and strategies among the partners are reached. A set of technical research priorities, both factor and commodity related, is generally well recognized and relevant to Strategic Objective 4, including:

- Water management and water use efficiency;
- Land degradation and measures for its control;
- Management and sustainable use of salt-affected soils;
- Farming systems research; and
- Agroforestry research and natural resource management.

With respect to water scarcity, three key issues were identified:

- Key Issue 1: Introduce crop varieties and management practices that result in better water productivity;
- Key Issue 2: Improve management of water resources and conserving the quantity of this resource through water harvesting; and

- Key Issue 3: Improve on-farm water-use efficiency and rationalizing the use of scarce water resources, especially through adapting new irrigation techniques and enhancing the uptake of improved irrigation technologies and practices in connection with irrigation scheduling.

Other important avenues that could greatly influence crop management are the adoption of conservation agriculture and water harvesting and developed related technologies. Large barley areas are under unfavorable growing conditions and high stress from pests and diseases. In 2008, ICARDA began engaging in focused partnerships to both develop and deliver improved genetic material and technologies to resource-poor farm families. These networks have strengthened partners' capabilities in addressing farmers' needs. They have also resulted in new genetic advancement, seed delivery and crop management approaches that are more effective and relevant in resource-constrained environments.

Thus, to summarize the research priorities for CWANA:

- A crop focus on barley (together with wheat);
- Emphasis on effective water and soil management;
- Strong attention to integrated pest management strategies: and
- A sharp focus on integrated natural resource and germplasm management.

Impact Pathway

The two primary outputs to be produced under Strategic Objective 4 (in close collaboration with Strategic Objective 1 and Strategic Objective 3) will yield several products that are focused on the key challenges faced by resource-poor smallholder farmers in dryland areas. These in turn will lead to research and development outcomes that will contribute to achieving key impacts (Figure 8). The work to be done under Strategic Objective 4 entails several gender dimensions (see Gender Strategy below), and gender disaggregated data and information (from Strategic Objective 1) will help shape field level work by DRYLAND CEREALS researchers and development specialists. Closing yield gaps and improving productivity under harsh environmental conditions is at the heart of this Objective, and iterative feedback and close working relationships with partners involved in developing improved varieties is essential for success.

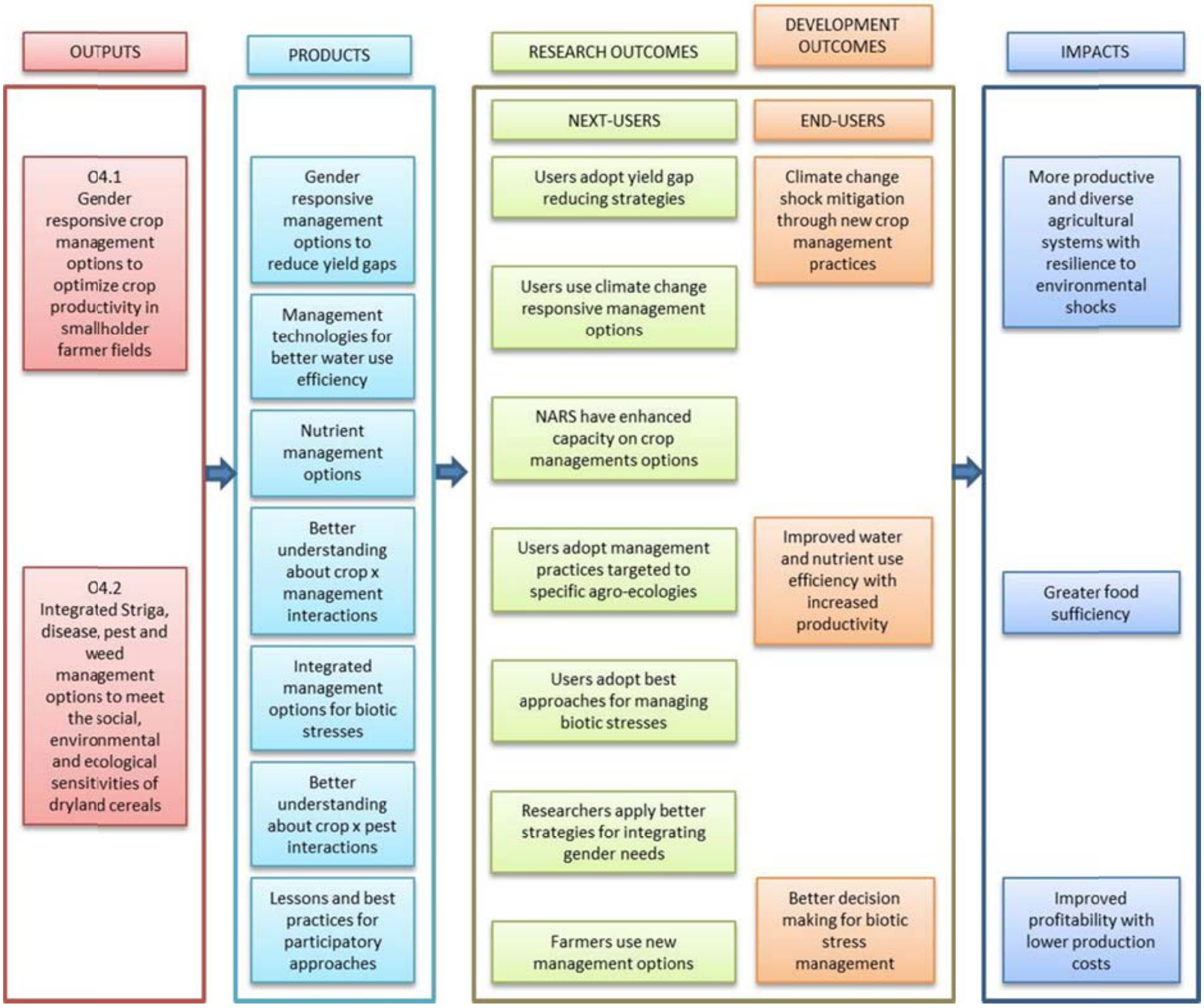

Figure 8. Strategic Objective 4 impact pathway

Key Partners

Developing sustainable crop management options, whether targeted at biotic or abiotic constraints, is by nature a location specific activity, and solutions are normally local rather than regional or global. Partnerships with farmers who are the ultimate validators and adapters/adopters of these technologies are required. Strategic Objective 4 will therefore engage in many partnerships at local and regional levels with organizations competent to work directly with farmers and who are experienced in conveying knowledge intensive management processes to them (see Appendix 4 for details). In each of our regions, the initial DRYLAND CEREALS partners now work with many such organizations, especially on seed systems, fertilizer microdosing, and watershed management, and these links (as well as others to CRP 1.1 partners) will be strengthened. Partners who are involved in the generation of crop management technologies, including NARES and in some cases ARIs will also be key partners.

Gender Strategy

Gender and crop management tasks – In most parts of the world, men and women tend to work at different tasks. Numerous time allocation studies have examined which household members perform which farm tasks (Hirschmann and Vaughan, 1984; McSweeney, 1979; Pala, 1983). These studies often identify some tasks as men's tasks and others as women's tasks. For example, in Kenya women reported that men were responsible for building the granary, and women were clearly responsible for hand digging, weeding, harvesting, and transporting the crops (Pala, 1983). Although many tasks may be viewed as exclusively women's or men's, in practice the divisions are blurred, and both men and women are involved. Relatively few tasks are done only by men or only by women (Doss, 1999). That women throughout Africa tend to provide more labor for agriculture than men – and almost always provide more total labor – has implications for crop management technology adoption. Even if they know they can increase productivity, women may be unable to increase the number of hours that they spend working on the farm. Simple comparisons of hours worked do not capture issues related to the type of work being done and the energy expended. The value of time will vary by season and task; thus, people will be interested in saving the time that is the most costly (Levi, 1987). However, to the extent that the tasks vary by gender and the value of women's time is lower, farmers may be more inclined to adopt technologies that save men's time. This scenario will be examined under Strategic Objective 4, specifically related to crop management, and will be linked with relevant Strategic Objective 1 research activities.

Gender and soil fertility management interventions – Soil fertility is a component of soil health, along with organic matter content. A critical entry point for improving soil productivity and reducing hunger is the adequate location-specific choice of crops and crop management practices. Women, especially if they are the main providers of staple foods crops, are particularly affected by declining soil fertility because they have limited access to external inputs such as chemical fertilizers.

The use of animal manure, legumes, living mulch, crop rotations, soil and water management practices, the choice of suitable crops for the farming environment, composting, conservation agriculture and other technologies that enhance soil fertility is traditional in many farming systems (Uphoff, 2002). However, despite the recognized importance of low external input strategies, chemical fertilizer remains the basis of soil fertility management in many farming systems and most intensification trajectories. Resource-poor farmers cannot afford to apply fertilizer at high rates, and combining fertilizer use with other soil productivity management strategies could further improve the stability and resilience of dryland cropping systems. Involving women in soil fertility management innovations is a key approach for Strategic Objective 4 and gender-disaggregated data relative to this work – obtained in concert with Strategic Objectives 1 and 3 – will help reveal the impact of interventions from a gender perspective.

Gender and crop protection interventions – Twenty to forty percent of the world's potential crop production is lost annually to weeds, pests, and diseases (CropLife International, 2007). Decisions about crop protection strategies must rest on expected returns to investment, which varies considerably across environments. In our marginal target environments the generally small returns to expensive chemical inputs make them difficult for farmers to justify (IFAD, 2002). Pesticides can increase productivity, but when handled improperly, they can be toxic to people. The key gender issues are:

- *Gender and knowledge of pesticide risks* – Compared to men, women are less informed about safe pesticide practices and the dangerous side effects of pesticide use; they also have difficulty in obtaining appropriate protective gear (London and Baillie 2001). Other gender issues include high costs of pesticides and render them prohibitive to women, and inconsistent benefits of alternative pest control technologies across socioeconomic groups.
- *Pesticide exposure* – Women and children are often directly or indirectly involved in crop protection work, and their limited access to information about safe pesticide use imperils their health and poses an environmental hazard. Strategic Objective 4 will strive to create awareness about and minimize associated risks of pesticide use.

Gender, knowledge and information differences – Men and women accumulate very distinct and rich sets of agricultural knowledge and skills as a result of gender divisions in the tasks they undertake, such as seed management and conservation and pest and disease management (Harwood et al., 2003). In making decisions about their livelihoods, men and women have different perceptions of what is important. They base their decisions on information from different sources. The unequal power relationships between men and women must be understood to achieve equitable development and the full participation of women. Interventions must be developed based on a comprehensive understanding of the needs that women and men identify to improve their situations.

Thus the gender strategy for Strategic Objective 4 focuses on developing clear and sound pathways to enhance food security and income generation for poverty reduction. We propose to set up appropriate gender participation targets with our partners and invest in enhanced female leadership and capacity within local partner implementing agencies. Strategic Objective 4 will work with Strategic Objectives 1 and 3 to address gender-specific barriers to resources, opportunities, and benefits through various activities, including:

- Gender-disaggregated analyses of livelihoods and access to key resources, including information and finance, among resource-poor farmers using standard gender analysis frameworks including the Harvard, and the World Bank tool kit and female empowerment frameworks;
- Using gender-sensitive research questions in order to collect information about the differences between men’s and women’s activities, roles, and resources in an effort to identify their developmental needs;
- Assessment of roles of men and women along the whole value chain by analyzing quantitative and qualitative information on all activities;
- Establishing gender-related targets on partnerships for impact, as many local partner organizations tend to exclude women (e.g., farmer’s organizations);
- Developing gender-specific monitoring and evaluation (M&E) indicators (such as women’s control of agricultural decision-making, and their participation in leadership positions in farmer organizations);
- Obtaining gender-disaggregated data on participation of men and women in training in integrated pest and disease management; and
- Identifying gender differences in workload as a result of introduced practices or new crop production technologies.

Innovations

Strategic Objective 4 will employ state-of-the-art approaches to research aimed at determining how to close yield gaps in harsh dryland environments, building on work done by others but often under less severe production conditions. For example:

- Conservation agriculture has been thoroughly tested on crops other than dryland cereals; Strategic Objective 4 will evaluate the feasibility and effectiveness of using conservation agriculture practices with dryland cereals in different regions and farming systems:
- Fertilizer microdosing will be evaluated for its effectiveness as a low input technology with our crops in different regions and farming systems;
- Fertilizer use (microdosing) in combination with other soil productivity management strategies will be evaluated, including the use of mulches, composting techniques, cover crops, and intercropping to further improve the stability and resilience of the cropping system;
- Fertilizer microdosing using water- and nutrient-efficient cultivars coming from Strategic Objective 3 partners will be assessed;
- New cropping systems using legume varieties from CRP 3.5 that fit short season windows will be assessed; and
- Integrated approaches to biotic and abiotic stresses (Striga, downy mildew, headminer, stemborer) will be evaluated. ICARDA has been testing different barley genotypes under zero and conventional tillage conditions for the last three seasons under Mediterranean agricultural conditions where soil moisture is a critical problem This technology may prove useful in countries like Ethiopia where plowing is done by oxen-drawn implements. When animal feed is in short supply, it is difficult for farmers to properly prepare their land. In this context, conservation agriculture has been identified to be very important for women-headed rural households (Giller, et al., 2011).

Outputs and Milestones for Strategic Objective 4 (further details are in Appendix 4)

4.1 Gender responsive crop management options to optimize crop productivity in smallholder farmer fields

The primary purpose here is to provide technologies to farmers that are directly linked to maximizing the yield of existing cultivars and exploiting the genetic gains of new cultivars generated under Strategic Objective 3. Yield gap analysis clearly shows that yield and production of dryland cereals can be increased, even by smallholder farmers in harsh environments, often with existing technologies and at affordable prices.

Milestones

- Studies conducted to identify available crop cultivars and management options for each dryland cereals per region and per farming system and a brochure of the same published and made available (2012)
- On-station and on-farm testing of different rates of micro-doses of fertilizers evaluated and optimum rates established and options for soil-water management demonstrated for each dryland cereals by region and farming system (2012)
- Training needs for stakeholders identified and disaggregated by gender (2012)
- Implementation of CBFFS for development and testing of integrated management of the main abiotic and biotic constraint(s) in 2 countries for 2 the two most important farming systems in each region (2013)
- Protocols for testing integrated crop cultivar and management using participatory approaches developed and tested to determine 3 methods for scaling out to other areas with similar production systems (2013)

- At least 3 best-bet crop management options identified using large-scale, gender-specific, farmer-participatory multi-location testing approaches for increasing hybrid productivity (grain and stover) in drought prone environments (2013)
- Location-specific improved production technologies tested (crop cultivars and soil-water-fertility management) for productivity and weed management (2014)
- Guidelines developed for optimization of soil fertility/organic matter management, including weeds, in at least 3 specific dryland cereal production systems, with varying levels of livestock integration (2014)
- Management options identified on a barley cropping system to minimize the detrimental effects of salinity (2014)

4.2 Integrated Striga, disease, pest and weed management options to meet the social, environmental and ecological sensitivities of dryland cereals

The use of improved varieties alone is not sufficient to achieve the productivity levels required to meet the food and income needs of smallholder farmers. Insect pests, *Striga*, diseases, non-parasitic weeds are serious constraints of dryland cereals productivity and production and utilization, and we will explore a number of crop management practices that can help control biotic and abiotic losses.

Milestones

- CBFFS for development and testing of integrated management of *Striga* and soil fertility in at least 2 countries for the two most important farming systems in each region (WCA and ESA) (2012)
- Intensive training on IPM and IDM options conducted with special emphasis on bio-pesticide production and utilization for at least three crop pest/disease combinations in specific production ecologies (2012)
- Integrated management of Russian wheat aphid on barley developed and tested in two countries for the CWANA and ESA each regions for the dryland cereals infested by striga (2012)
- Integrated shoot fly management options fine tuned for various production areas (2013
- Weed management options compared in at least 2 farming systems, disaggregated by gender needs, including monitoring health and environmental effects of increasing herbicide use in dryland cereal cultivation (2013)
- 200 farmers/country participate in Farmers Field Schools (FFS) on integrated Aphid management on barley in Ethiopia and Eritrea (2013)
- Interaction of nutrients and bio-agents with host genotype studied to select combinations that elicit systemic resistance against the key pests in sorghum and pearl millet (2014)
- Integrated *Striga* management options developed and tested in ESA and WCA, and shared with the NARS partners and integrated shoot fly management options fine tuned for various production areas (2014)
- IPM/IDM systems for the management for at least three crop pest/disease combinations developed for specific production ecologies (2014)
- Lessons learned and best practices for effective large-scale participatory integrated crop management practices published, and selected women and men farmers' knowledge in assessing the cultivars and management practices enhanced (2014)

Strategic Objective 5: Enhancing effective seed and information systems for better delivery of improved technology packages to smallholder farmers

Rationale and Description

Strategic Objective 5 focuses on enhancing a more effective and efficient seed and information delivery systems that will enhance the availability of improved technologies to smallholder farmers in Africa and Asia. Weak seed delivery systems, coupled with high prices for and poor availability of fertilizers, as well as limited state support and extension services for dryland farming, remain major constraints for realizing the benefits of international and national research in farmers' fields in many developing countries.

It is estimated that improved varieties are planted on approximately on 34% and 23% of the total area of millet and sorghum in SSA, respectively. However, studies found that sorghum and millet varietal adoption is dismal in western Africa (Ndjeunga, 2002; Diakité et al., 2008) and eastern Africa (Mekbib, 2006; Alemu, 2010) and as low as < 3% in Ethiopia (McGuire, 2007), a major regional sorghum producer. Similarly adoption of improved barley varieties still remains low in the CWANA region (Bishaw, 2004; Aw Hassan et al., 2008).

While availability of hybrid seeds of sorghum and millets through the private sector may hold promise in India (Matuschke and Qaim, 2008), elsewhere most dryland cereals research and seed delivery is dominated by the public sector. To date, neither the public sector nor the emerging private sector have effective delivery strategies for getting seed of improved varieties to smallholder farmers in less favorable areas and remote regions where dryland cereals are grown. For example, the formal seed sector provides less than 6% for barley producing countries in CWANA (Bishaw, 2004), for sorghum and millets in western Africa (Ndjeunga. 2002; Diakité et al., 2008) and for sorghum in eastern Africa (McGuire, 2007).

Governments must create an enabling policy environment to improve the efficiency of national seed systems and promote diverse forms of delivery systems, including the public and private seed sectors and innovative ways of decentralized farmer-based seed production and marketing, which involve farmer groups/communities and NGOs operating in the country. Equally important are institutional innovations for improving farmers' efficient and timely access to dryland cereal technologies, input markets and services.

Most farmers in the dry areas of the developing world still do not benefit fully from the information and knowledge generated by international centers and NARES partners due to weak transfer of agricultural technologies. Hence the availability of new dryland cereal variety and seed should be accompanied by associated agro-inputs and crop management technologies to realize their full potential during crop production. Farmers (women and men) should be aware of and have access to new varieties and associated agronomic practices, agricultural inputs, and post-harvest technologies and be able to use them. Lack of inputs and accurate and up-to-date information on new agricultural technologies continues to be one of the major constraints to agricultural productivity and production of dryland cereals. McMullen (1987), for example, suggested that extension must create linkages between plant breeders and farmers through seed producer demonstration plots.

Lessons Learned

Several key lessons have been learned from past efforts to improve the delivery of seed and information to smallholder farmers:

- Participatory plant breeding is able to identify farmer's preferred traits and selection criteria, which increased adoption of barley varieties in dryland areas (Ceccarelli and Grando, 2007);
- Local seed production through village-based seed enterprises has been successful in introducing new crop varieties to farmers, in producing quality seed at the local level, and has proven profitable and sustainable (Srinivas et al., 2010);

- Initial assessment of seed diffusion in Mali confirmed that sorghum varieties are primarily being adopted, not through commercialization efforts, but rather through mini-kit trials, with diffusion to other households occurring through social networks. In southern Mali, for example, significantly more improved varieties are used by farmers living in villages were variety testing activities are carried out (Somé, 2011);
- Women are mostly excluded from informal seed exchange, and information regarding new varieties does not reach many farmers, both women and men. Studies showed that 30-70% of women farmers get seed from their husbands and from their own harvest (Somé, 2011; Ehret 2010; Siart, 2008). Less than 10% of women get their varieties from a farmer organization or from seed cooperatives (Somé, 2011);
- Rural radio appears to be an effective means for information diffusion. For example, in Niger 50-90% of seed sales are due to radio messages (Dr Ignatius Angarawai, pers. comm.). Better quality reporting about improved varieties, specifically for hybrids, is needed;
- Using mini-kit trials to increase awareness and diffusion of improved sorghum and millet varieties in WCA seems to be effective in reaching famers in a range of production systems and from a variety of social backgrounds;
- Links between seed producers and agro-dealers are strengthened through sale of mini-packs in input shops; and
- Adoption of new sorghum varieties also increased because of improved stover quality (Falconnier, 2009).

Key Partners
A number of regional and international organizations with a strong interest in seed value chains for dryland cereals will partner in research relating to the delivery of inputs and relevant information (Appendix 4). Many public-private research partnerships for seed sector development have been emerging in recent years. Partnerships are being forged between: multinational companies and domestic seed companies; CG centers and national seed companies or with NGOS promoting specific value chains or seed initiatives/access to inputs: public NARES and small private seed companies; and between donors and international/public research. Such partnerships include germplasm development and exchange, accessing new technologies (including biotechnology), and/or technology transfer through exclusive license to multiply and commercialize varieties resulting from the partnership, subject to royalties or exemptions. Depending on the specific partners involved, different modalities of public-private partnership will be used and the lessons learned in each case and from others will be applied.

Priority Setting
The seed system research proposed here focuses on the WCA, ESA, CWANA, and SA regions. They collectively represent the major dryland cereals production regions dominated by small-scale producers where adoption of new crop varieties is low, formal seed supply systems are largely non-existent, and the use of agricultural inputs is minimal. Moreover, with the failure of the formal sector (public and private) alternative approaches are being tested, from varietal development to agricultural technology transfer to seed production and marketing to agro-input supply working with farming communities. The overall objective is to increase availability of, access to, and use of adapted improved crop varieties and associated technologies and agro-inputs. This requires an understanding of existing situations through comparative analysis and country case studies along the seed value chain and the design of alternative options to create a diverse and competitive seed system. Periodic monitoring and evaluation is necessary to measure the performance of formal (public and private sector) and informal (farmer/community) systems in ensuring varietal diffusion and adoption, and access to quality seed and other agro-inputs by farming communities**:**

- Comparative analysis and country case studies would be conducted for barley seed systems in Central and West Asia and North Africa region, including Ethiopia in East Africa, where barley is a major crop with serious constraint in seed delivery system;
- Improve women (and men) farmers' access to seed of new sorghum and pearl millet varieties in targeted regions of West Africa (Niger, Burkina Faso and Mali) using different strategies, such as a large number of mini-kit variety tests, participatory variety trials, mini-pack diffusion, seed production, and commercialization activities;
- Monitor and enhance variety adoption processes in the target zones in order to assess effectiveness of the different activities to enhance seed availability and knowledge about the new varieties. Focus on variety changes, target groups, seed systems (formal, informal) in Mali, Burkina, Niger;
- Support emerging farmer-based seed enterprises through training in seed production technology, marketing and promotion, and financial and seed business management;
- Support the development of harmonized seed policies and regulatory frameworks by regional economic blocs (ECOWAS, SADC, COMESA, etc.) and regional seed alliances (e.g., the West Africa Seed Alliance); and
- Develop and improve information pathways for effective diffusion of information and knowledge on new technologies, including new varieties, agronomic practices, and agro-inputs.

Impact Pathway

There is strong interface between agricultural research and seed delivery (Figure 9). New crop varieties are defined outputs of collaborative research, with NARES one of the key pathways for delivering the technology and realizing the impacts of investment in national and international agricultural research. Strengthening the seed systems addresses one of the key constraints in technology delivery by enhancing the efficiency of the formal public seed sector and encouraging private sector participation, as well as improving the performance of the informal sector through innovative decentralized farmer-based seed enterprises. Availability and access to seed of adapted dryland cereal varieties is critical in increasing agricultural production and productivity and thus contributing to better food security, reduction of poverty and improving rural livelihoods. This is particularly relevant for the majority of smallholder resource-poor farmers in the dry areas who are entirely dependent on agriculture for their livelihoods. The seed value chain approach will play a catalytic role by creating functional linkages among: international and national research centers that provide the new germplasm; seed producers and suppliers that deliver inputs; the "seed-using" farmers producing surpluses for markets; agroprocessors that produce value-added products; and consumers that have better choices. This allows improved flow of technology and information along the production-to-market value chain, which in turn should lead to greater impacts.

New crop varieties and associated technologies of dryland cereals would be developed through both conventional and participatory approaches in target regions. These new varieties and technologies would be popularized and demonstrated through effective extension services (or farmer organizations and NGOs as in West Africa where the extension service has strong operational limits) to create awareness among farming communities. The agro-input-providers would make available required inputs. The varieties and seeds move from research centers through formal and informal channels making available quality seed to farming communities (Figure 10). It is expected that liberalization and commercialization of the formal sector would create a competitive public and private industry whereas on the other hand farmers are mobilized to form decentralized farmer-based seed enterprises that can produce and market seed locally and compliment the formal sector.

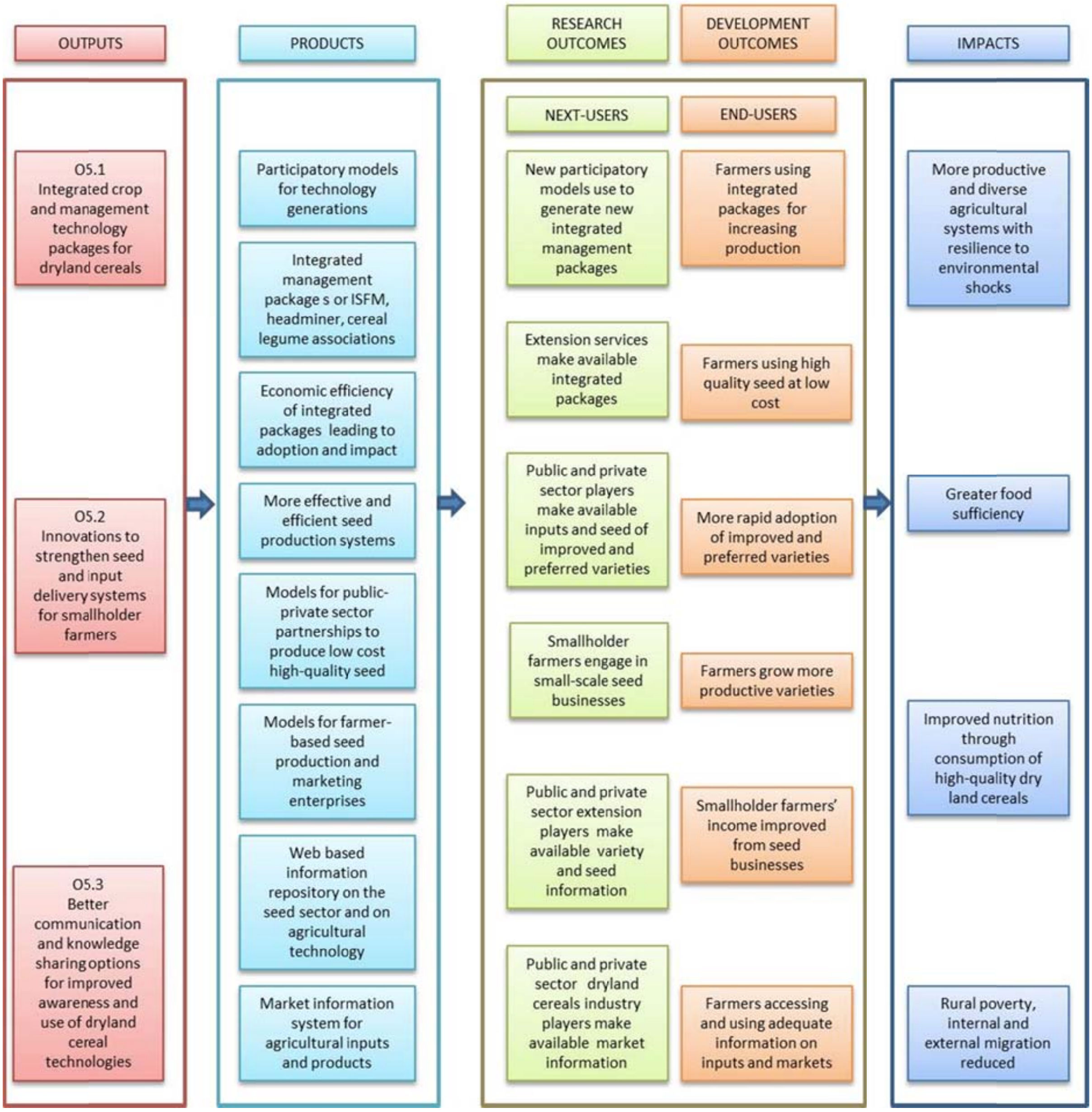

Figure 9. Strategic Objective 5 impact pathway

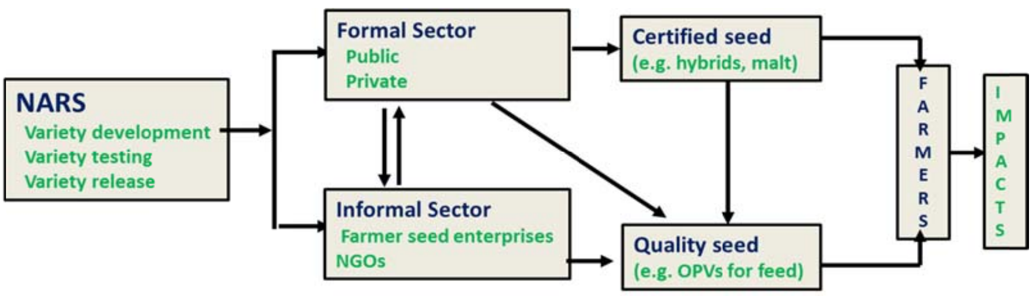

Figure 10. Movement of improved seed from national research centers through formal and informal channels to reach smallholder farming communities

Innovations
Developing sustainable seed and input delivery should combine research components to address seed/input system constraints, and development components to facilitate technology transfer, its adoption and diffusion through provision of improved varieties, seeds and inputs.

Seed system innovation along the seed value chain will include:

- Recognizing the roles of formal and informal sectors and building on their comparative advantages, synergies and complementarities to promote diversified seed systems tailored to specific country situations. To date, for example, members of WCA farmer organizations are producing certified seed alongside government organizations and seed enterprises.
- Emphasis on commercialization and market orientation of the public seed sector. A clear understanding of effective demand for seed of improved varieties is needed in order to measure the size of the seed market.
- Promotion of private sector seed delivery. Introduction of hybrid varieties (sorghum, millet) with better yields, particularly in Africa, would encourage entry of the private sector, compared to OPVs where the informal sector predominates.
- Promotion of farmer-based seed production and marketing enterprises. A multi-stakeholder process is needed for organizing and supporting local-level seed production and defining relative roles and responsibilities to ensure sustainability.
- Seed marketing in mini-packs. Generally seed is marketed in larger quantities that do not fit farmers' needs. We will encourage farmer experimentation with new varieties and with "seed purchasing," including agro-dealers in the sale of mini-packs for crops.
- Linking participatory variety development to seed initiatives by collaborating with development agencies and NGOs in large-scale variety testing (test-kits) and assuring seed availability of preferred varieties by supporting and creating local seed initiatives, creating demand and assuring sustainable availability.
- Rationalizing and/or harmonizing regulations and procedures. While progress is at different levels in different regions, DRYLAND CEREALS will provide a platform for regional approaches to technology generation, facilitate the flow of germplasm and varieties across borders, and encourage private sector investment.
- Using new communication tools and techniques, such as radio, TV, video messages, leaflets, brochures, farmer field schools, and farmer visits. Women farmers will be a particularly important target for this work.

Capacity Strengthening
Strengthening NARES capacity along the seed value chain remains critical. The focus should be on improving physical facilities and human resources to impart knowledge and to enhance the performance of delivery systems. For example, NARES require critical facilities and equipment to establish functional seed units responsible for early generation seed production to ensure availability of breeder and foundation seed of newly released varieties. Whereas the public seed enterprises suffer from dilapidated processing and storage facilities, the emerging private sector entities lack capital and credit to establish adequate facilities for quality seed production and marketing. A critical assessment of infrastructure needs in target countries will be made and avenues for provision sought in partnership with development partners.

Strengthening the capacity of human resources is the best strategy to transfer knowledge about available agricultural technologies. Short-term technical courses on seed technology, post-graduate studies, and workshops/seminars should focus on the formal (public and private) and informal seed sectors. These courses should to be module-based, target technical managers, and include themes on seed production, processing and quality assurance, as well as seed enterprise development and management. Moreover, post-graduate studies need to be explored to develop a cadre of young generation of seed technologists who will manage and lead the national programs in understanding and developing dryland cereals seed systems. These should be complemented by workshops and seminars targeting policy makers and senior managers to create awareness and advocacy to support the dryland cereal seed sector.

Training is also needed to instruct and advise private seed initiatives (seed companies, farmer-based seed enterprises) in the application of seed policies. Drastic seed law changes are often difficult to adapt to local farming system situations (e.g. the recent changes in West Africa requiring a minimum of 3 hectare fields, high prices for registration and certification, etc.).

Gender Strategy

Women tend to be the seed guardians in rural communities and households, and play a critical role in agricultural development. The traditional role of women as seed selectors and preservers is widely recognized. The local seed system analysis provided highlights of gender roles in on-farm seed production and management, and place women in key position for participatory variety selection and seed production.

In most rural communities, women participate extensively in crop production and agricultural wage labor. A significant proportion of female-headed households are also engaged in agricultural production in many developing countries. Despite their significant role, however, women are confronted with such constraints as lack of access to land, capital, credit and other resources that limits their adoption of new technologies. Women have been found to be owners of local seed enterprises, and demonstrate greater responsibility in the management of their businesses (David, 2004). Women farmers will be targeted for accessing seed of new dryland cereal varieties and women entrepreneurs encouraged to form alternative farmer-based seed production and marketing enterprises envisaged within the seed initiative. This could be linked to on-farm processing and value addition of dryland cereals food products operated by women.

In Mali, sorghum, although traditionally considered a “men’s” crop, is actually cultivated by women and is frequently used to assure food for their young children. Thus access to quality seed, specifically to bio-fortified varieties (zinc, iron), would be crucial for family health.

Outputs and Milestones for Strategic Objective 5 (Appendix 4)

5.1 Integrated crop and management technology packages for dryland cereals

In order to increase adoption and yield in farmer’s fields, varieties need to be packaged together with appropriate crop management practices that fit farmers’ production systems. Such technology packages need to be tailored to differing socio-economic conditions in each region and they must respond to gender differences.

Milestones

- Variety and hybrid demonstrations linked to input suppliers in SSA (2012)
- Integrated technology packages tested in three regions tested (2014).
- At least one technology package specifically adapted to meet women farmers’ needs in each region developed (2014)
- Economic evaluation for integrated technology packages (2014)
- Impact assessment for one cereal crop in each region conducted (2014)

5.2 Innovations to strengthen seed and input delivery systems for smallholder farmers

Past efforts to strengthen public agricultural research and seed delivery along the “seed chain” have had limited success. A lack of market-orientation, coupled with weak institutional linkages along the chain, impedes progress. The dryland cereals seed sector is at different stages of development in different countries, and within and among regions. Understanding these seed markets is essential for developing new options for improving them. Similarly, input delivery systems will be assessed in terms of policies, institutional arrangements, and marketing services.

Milestones

- Review of existing alternative seed delivery models conducted and results made available; and technically and economically viable pilot farmer-based seed production and marketing enterprises established and their sustainability evaluated in at least one country in each region (2012-13)
- In-depth analysis of national seed system for dryland cereals completed in at least one country in each region and lessons drawn and recommendations made to national governments (2013-14)
- Review of early generation seed production completed and functional seed units and procedures established in at least one country in each region to ensure availability and access to foundation seed working with public sector, seed cooperatives and private sector (2012-13).
- Review of infrastructure and equipment needs completed in at least one country in each region and critical needs addressed in partnership with development partners and personnel trained in seed science and technology (2013-14)
- National studies on the technical efficiency of public- and private-sector dryland cereals seed production completed in at least one country in each region including seed cooperatives in Mali, Burkina Faso in WA (2012-14)
- Support to harmonized regulatory framework on variety release, seed certification, phytosanitary measures, etc. within regional economic blocks (COMESA, ECOWAS, SADC, etc.) implemented (2014-15)
- Existing agricultural input supply systems (fertilizers, etc.) is conducted, results become available and systems strengthened to increase farmer access to inputs for dryland cereals in Mali, Niger, Burkina (2013)
- Assess the efficiency of diffusion schemes targeted on women (2012)

5.3 Better communication and knowledge sharing options for improved awareness and use of dryland cereal technologies

A large number of smallholder farmers do not benefit from the information and knowledge generated by research, in part because of poor agricultural extension systems and limited, uncoordinated international and national support for knowledge dissemination, but also because of the limited capacity of national programs to take full advantage of new information and communication technologies. Options for overcoming these obstacles in remote dryland areas are needed, and will be a primary output of Strategic Objective 5.

Milestones

- Agricultural extension systems reviewed, key gaps identified and recommendation made to NARS (2012-13)
- ICM policies and strategies for agriculture and rural development sector formulated and implemented (2012-13)
- Web-based information repository on seed sector including variety catalogues, field and seed standards, directory of key seed sector stakeholders, etc. initiated along coupled with newsletter for sharing information and creating awareness across the regions (2014)
- Develop web-based information repository on agricultural technologies for dryland cereal production and shared on open and collaborative mode (2014)
- Market information system for agricultural inputs developed including fertilizer providers, etc. (2014)

- Market information system for agricultural products developed including dryland cereals products, agro-processors, etc. (2014)
- Train farmer organizations, NGOs and NARES in developing and producing radio and video messages

Strategic Objective 6: Adding post-harvest value and improving market access of dryland cereals to provide smallholder farmers more benefits from dryland cereals

Rationale and Description

Strategic Objective 6 targets value-added products and the necessary research to ensure that smallholder farmers can benefit from added value, increased market demand, and more readily accessible information on production technologies and options for accessing them. The first and most widespread opportunities derive from focusing on the integration of food with fodder, and possibly feed production. Fodder and feed can be marketable surplus, if it has the desired qualities, and is available when demand is high. Processing options (pre-treatments) that render the dryland cereals amenable for use in the food processing industry, to develop different value-added products, needs to be identified, in close collaboration with Strategic Objectives 2-4. These products should be competitive with other processed staples and value-added products, such as from rice, wheat, maize grits, pasta or cassava flour. Research, done in close collaboration with Strategic Objectives 2-5 is required for the development of such products, and their subsequent marketing, including the necessary business development activities to ensure availability of such marketable products in areas where potential buyers can be targeted and thus providing them access to these value-added products. Appropriate strategy and business models need to be adapted for marketing and promotion of these newly developed food products with the food industry (models identified under CRP 2 could be tapped for this). Special attention needs to be given to also adapt suitable value chains for providing quality and consistent supply of grains to the food industry at a competitive price. Such research and business activity is long-term in nature, and requires collaboration with the academia and the private sector in various domains.

Women will benefit by reducing the time required for and drudgery of post-harvest processing, and from new business opportunities for producing and marketing value-added products based on dryland cereals. However, smallholder farmers, especially women, will benefit from such market opportunities, only if specifically targeted measures are taken. Many of the target countries are among the poorest in the world, with the lowest human development indices; poor infrastructure, especially in rural areas; low literacy rates; and aging NARES, with decreasing numbers of qualified staff. Strengthening capacity locally to encourage innovation, managing change and effective communication thus presents a major challenge. Engineering and food processing research and manufacturing are poorly developed in most of our target countries.

Innovations that improve farmers' chances to derive benefit from these markets will impact a very large number of producers. This component will be oriented towards improving famers' skills at benefiting from these markets, by improving their capacity to produce surplus with better production technologies, mainly developed under Strategic Objectives 2-5, by improving their understanding of the functioning of these markets, improving access to market information, as well their capacity to store grain successfully, possibly with the option to benefit from inventory credits, to facilitate improved access to input markets as well.

To tap these demand-led opportunities, farmers in the drylands need access to new cereal varieties specifically developed with appropriate combinations of food, feed and fodder traits under Strategic Objectives 2-5 for use in crop-livestock systems, which will increase farmers' access to markets and income from the sale of grain, feed and fodder.

Lessons Learned

Several key lessons will guide the development and implementation of Strategic Objective 6:

- Communication and trust is an important element of successful linkages between farmers and industry both in formal (written agreements) and informal (verbal) contracts.
- Innovation is possible when all stakeholders in the value chain are fully aware of the implications of new technologies and products in a clear and transparent manner, i.e., not couched in scientific jargon.

- Knowledge regarding processing options exists in some local communities where respective dryland cereals are grown (e.g. for finger millet snacks in Western Kenya). However, knowledge about the preparation of such products is not yet documented and distributed, and processing only takes place occasionally on a small-scale. Moreover, processing options still need to be optimized, especially in regard to a longer shelf life for these products.
- Although processors in, for example, Northern Tanzania, have specific quality requirements for dryland cereals, farmers in Central Tanzania are not aware of those. Suitable value chains need to be developed to ensure that information flows between processors, intermediaries, and farmers.
- The nutritional value of finger millet, pearl millet and sorghum is increasingly recognized in several countries in ESA and India. However, it is often only a certain group of consumers (elderly persons, sick persons) who value and consume these products, though that appears to be changing, especially in SA. Strategies to promote the consumption of dryland cereals to a broader spectrum of consumers are still needed.

Priority Setting

Strategic Objective 6 will place its initial priority on decreasing post-harvest losses due to improper drying, handling and storage. Improving the long-term storability and maintaining quality for the harvest is crucial if farmers are to increase quality food availability and to potentially enter into market opportunities. Priorities for crops, regions and specific interventions will be based on knowledge gained from Strategic Objective 1, as well as priorities established by NARES in the target countries. As regions and countries are determined to have adequate post-harvest capacities, attention can be focused more on developing possible market linkages. Again, outputs from Strategic Objective 1 will help guide the focus for potential novel dryland cereal-based products. Setting priorities will require discussions not only with NARS, but also with potential food and feed industries in each target region. As markets are identified, efforts will be undertaken to research appropriate products and to develop required linkages to such markets. We believe that this area will be extremely dynamic and require constant attention to opportunities and setting priorities. Effective communication across the CRP will be critical for proper research to be prioritized – a critical role for the RMT.

Impact Pathway

The activities under Strategic Objective 6 will produce a range of outputs: processing technologies, new improved grain and fodder products, and more nutritious products that can lead to useful impacts (Figure 11). They will be demand driven, and derived in participatory ways with smallholder farmers, development partners and others.

Our development partners are the primary “delivery mechanism” to improve smallholder farming operations and related processing and marketing activities. In order to have maximum impact, we help create an environment in which smallholder farmers can produce marketable surpluses and in which they can gain access to more efficient and effective markets, access that can transform surpluses into additional income and open opportunities for establishing commercially viable SMEs and/or link directly with agro-industries. Beyond that, we must work through development organizations, educational institutions and governments to further educate consumers about the nutritional value of these crops, an “awareness trend” that is picking up speed in South Asia and holds similar promise in Africa, both in rural and urban areas. As consumers increasingly partake of coarse grains, whether in the form of traditional foods or as new, timesaving processed food products, the demand for additional surplus production will continue to increase.

We also need to know how to create market opportunities that can benefit women, opportunities that lead to empowerment and improved livelihoods. Outputs relating to nutrition and food security are particularly relevant to women, as are those relating to improving feed and fodder quantity and quality since women often care for household livestock. Improved processing technologies that make it easier for women to process food for home consumption, and to process it in larger quantities for storage, can help reduce drudgery and the workload handled by women.

DRYLAND CEREALS partners must consider the whole value chain to make sure different outcomes have the desired behavioral impacts on different actors. As noted earlier, we realize that participants along the value chain interact in a number of ways and that there is a multiplicity of feedback loops not shown here. The role of governments in creating enabling environments is also critical, as are gender considerations and capacity strengthening.

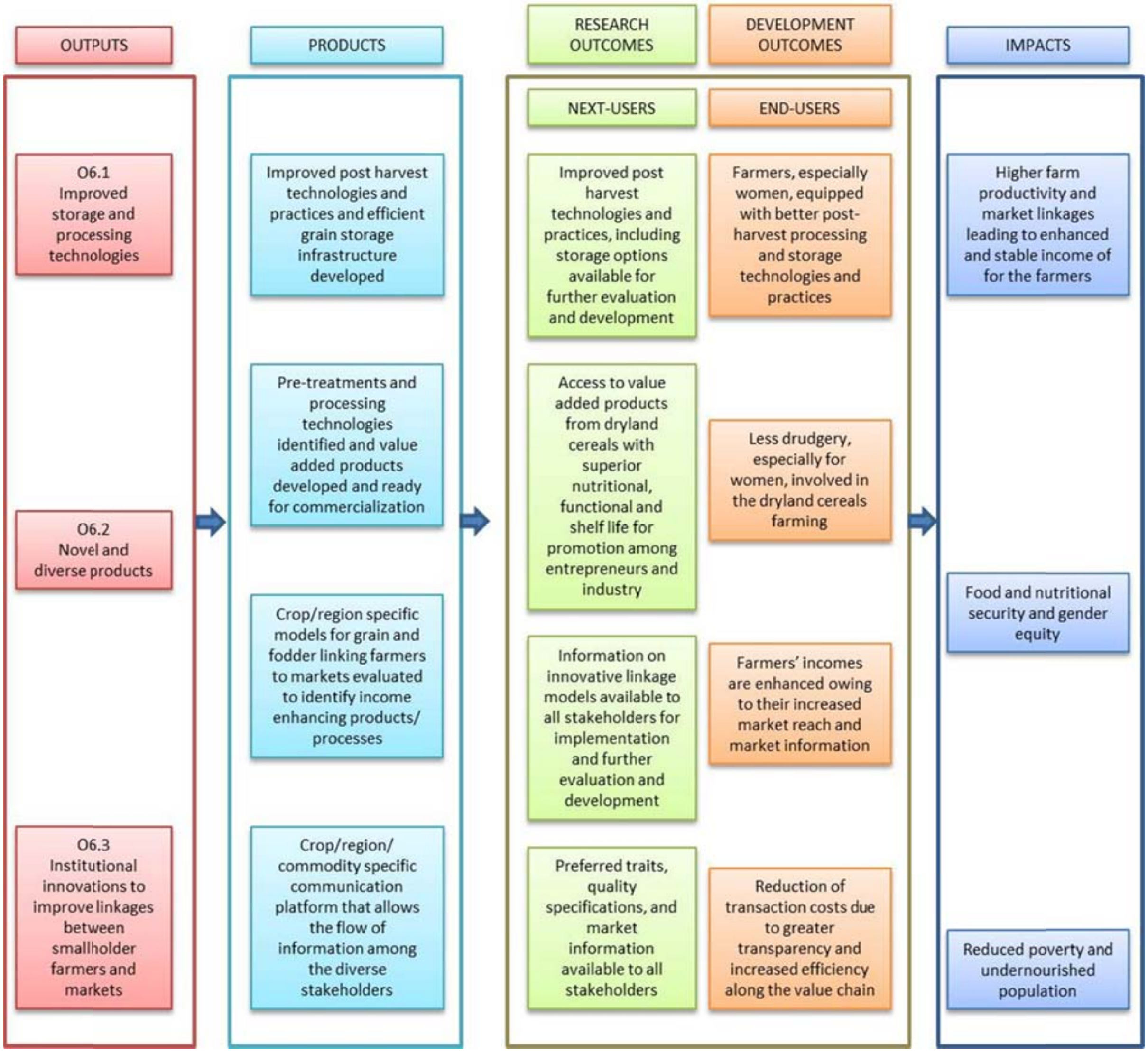

Figure 11. Strategic Objective 6 impact pathway

Key Partners and Their Roles

A wide array of both traditional and entirely new partnerships is envisioned under the auspices of DRYLAND CEREALS. Relative to this strategic objective, some of our key partners will come from both the public and private sectors, and range from advanced research organizations, to applied research and development organizations, to well-established and emerging businesses (see Appendix 4 for details). Private sector companies in the dryland cereal processing sectors, as well as in the seed sector, will be key partners, not only for creating research outputs, but also for facilitating large-scale outcomes. Moreover, in any particular value chain context it will be essential to involve key actors, such as input suppliers, extension services, development actors, credit institutes, and possibly consumer organizations. Success in creating significant new opportunities for market integration of smallholder dryland cereal farmers, specifically women, will rest on developing an array of new, non-traditional partnerships.

Gender Strategy

While dryland cereal crops tend to be considered food staples in most situations, and not cash crops, it is often women who generate income from marketing products processed or derived from them: traditional malted products, small ruminants or poultry fed on dryland cereal byproducts – straw, bran etc., or processed local foods, e.g. "fura" in Nigeria. Improving these value chains will help increase women's income.

Women dominate the processing sector for dryland cereals, both in the home, and for traditional food marketing. However this "informal" sector could benefit from technologies that enhance quality, business management skills, capacity for achieving economies of scale, and effective marketing. Thus we will investigate business models for spreading the use of threshers, mechanical "dehullers" or decorticators, as well as small-scale flour mills, in a manner that women can benefit from new business opportunities, not only from the reduction of drudgery.

Improving the availability of processed dryland cereal products in cities will also benefit poor urban women, who spend a lot of time preparing food for the family. Indeed, the labor for processing cereals into food for household consumption tends to be fully women's responsibility.

The long-term health effects of malnutrition are most serious for young children and for expecting and nursing mothers. Strategic Objective 6 will therefore focus much of its attention on these vulnerable groups, but will also address the general nutrition needs of others. To this end, we will adopt gender analysis and participatory methodologies that reveal the needs and preferences of women and men (differentiated by age) in relation to nutritionally enhanced varieties. Women and men have different nutritional needs at different stages in life, and these need to be taken into account to effectively enhance nutritional health in the households.

Malnutrition is related to food availability, access and distribution. Understanding the social dynamics regulating the access of different individuals to food (at the community and intra-household levels), or to the resources needed to purchase it, can support a more equal distribution of healthy and nutritious food. Social and gender analysis can provide insights into these community and intra-household dynamics through in-depth qualitative research.

Given their roles as food providers, women (both in rural and urban areas) will be involved in initiatives to increase awareness about the nutritional value of specific crops, and best methods for improving cereal storage and for preserving or improving nutritional properties while cooking. Men will be involved along with the women in these initiatives to ensure agreement at household level regarding food patterns and priorities. Men and women will be sensitized about the existence of value-added traditional and alternative food products.

Capacity Strengthening

To implement the technology options listed in the priority setting section for this Strategic Objective, capacity building for resource-poor farmers and communities will be crucial. Training activities will need to be focused on community needs, and methodologies will take into consideration the indigenous knowledge and local competences, thus amplifying stakeholders' interactions and exchange in efficient community setups, such as farm field schools, participatory group learning, etc.

Capacity building in the form of training and entrepreneur development programs (EDPs) for service providers (individual entrepreneurs, farmer organizations, small- and medium-scale entrepreneurs, food processing industries etc.) to deliver information on innovations, marketing and technology targeting will be important activities. Post-harvest issues and agro-enterprise development will be key, and emphasis will be placed on promoting women entrepreneurs. Such training will focus on both pre- and post-harvest operations, as well as on activities related to value addition and commercialization. Skills required for developing value added products will also be enhanced through appropriate training programs and workshops.

Innovations

Improving shelf life of dryland cereal products – Rapid rancidification of pearl millet flour (within 7-10 days after milling) is a major barrier in the commercialization of pearl millet flour-based products (Nantanga et al., 2008). This is relatively less of a problem in barley and sorghum, and there appear to be no studies on finger millet. Fortunately, there are processing technologies under development that can enhance the shelf life to several months. A new method that involves moist heating of the grain followed by drying to about 10-12% moisture and decortication appears to increase the shelf life of sorghum flour for up to 8-10 months, and pearl millet flour for up to 3-4 months. This technology could produce a breakthrough in the commercialization if it proves feasible for large-scale application. Furthermore, research suggests that there is genetic variation for rancidity-associated traits and for the tolerance of pearl millet flour to storage (Chugh and Kumar, 2004). Thus, opportunities exist to make improvements in shelf life from an approach that explores a crop improvement angle in combination with an assessment of processing technologies.

Linking farmers to industrial users – A coalition approach would be used for linking farmers to markets. The innovation systems model (Coalition Approach) recognizes a more diverse set of actors and relationships, e.g., farmers, scientists, public and private sector players, NGOs, research managers, line departments, and policymakers – each player contributing to achieve an overall purpose or goal. It is a model to link different institutional players for speedier and sustainable dissemination of technology for small-scale producers. The process in which distinct and/or independent entities and institutions work together as a single unit for the common goal with synergistic effect while keeping their identity [Gurava Reddy et al., 2007; Parthasarathy Rao et al., 2004; Ravinder Reddy et al., 2009 (2)]. The Coalition Approach provides an opportunity for the members to:

- Contribute knowledge in their respective fields;
- Work towards a common goal with clearly defined roles and responsibilities;
- Exploit the synergies of working in groups;
- Share the lessons learned;
- Respond to users expectations (especially for scientists to respond);
- Experience new strengths (i.e. farmers) in bargaining with industry, and for both to foresee additional complementary benefits.

Outputs and Milestones for Strategic Objective 6 (Appendix 4)

6.1 Improved storage and processing technologies to reduce post-harvest losses in quantity and quality

Effective and affordable drying, storage and processing technologies and practices will be identified through research under Strategic Objective 6 that can increase efficiency, reduce drudgery, and reduce post-harvest losses incurred by smallholder farmers in dryland areas.

Milestones

- Loss assessment due to storage pests and technology gap analysis in post-harvest management and storage completed for each crop and region (2012)
- Available drying technologies evaluated and compared with new innovative technologies and appropriate technology shortlisted based on cost-benefit analysis and implemented for each crop and region (2013)

- Appropriate equipment for threshing, winnowing, grading and decortication of each crop in each region identified and shortlisted, based on cost-benefit analysis of newly developed prototypes and comparison with existing technologies (2014).
- Varieties with resistance to storage pets in each crop identified, and other options for the management of storage pests evaluated (2014)
- Storage technologies for primary and secondary storage of grains evaluated and at least one technology implemented in each region for each crop and training in grain protection technologies and pest management practices imparted to farmers in the selected regions (2014)

6.2 Novel and diverse dryland cereal-based products to stimulate demand for grain

The use of dryland cereals in the food and feed industries can be increased by various processing treatments, including blanching, malting, dry heating and acid treatment, that can improve their shelf-life, nutritive value, sensory qualities, and other characteristics, and make them more amenable for development of value-added food products. Research aimed at identifying new options and potential products will thus be a feature of Strategic Objective 6.

Milestones

- Pre-treatment and packaging options optimized, using suitable varieties of sorghum and millets having desirable nutritive and processing traits, leading to shelf-stable sorghum and millets flour (2012)
- Pre-treatment and food preparation methods that maintain the nutritional value, improve digestibility and reduce anti-nutritional factors optimized and at least two value added products, targeting women and children (weaning foods etc.) from each cereal developed using these optimized methods in each region (2013)
- At least five different processing technologies evaluated resulting in the standardization of at least two value added food products each from sorghum and millets involving formulation optimization, nutritional and sensory profiling (2014)
- Packaging technologies and labeling protocols developed for commercialization of sorghum and pearl millet based food products (2014)
- At least two value-added food products based on sorghum and millets formulated and validated for retention of activity of their bioactive components, under optimized processing conditions (2014)

6.3 Institutional innovations to improve linkages between smallholder farmers and markets

Growing demand for high-value and ready-to-cook food is opening up opportunities for smallholder dryland cereal farmers to participate in different value chains, and the derived demand for coarse cereals is also increasing because of rapid growth in the livestock/poultry sector, as well as in the malting and biofuels sectors. There are apprehensions, however, about the capability of smallholders to participate in market-oriented production for high-value commodities and coarse cereals. Institutional innovations in marketing are needed not only to improve market access, but also the quality inputs, technology, information and services. Identifying such innovations will be an important output of Strategic Objective 6.

Milestones

- Existing institutional arrangements linking small holder farmers to grain and fodder markets identified and documented in each region, with special attention to women farmers/ processors (2012)
- At least two crop/region specific models for grain and fodder linking farmers to markets tested and evaluated on equity, social and efficiency parameters (2013)

- Establish at least two crop/region/commodity specific communication platform that allows the flow of information among the diverse stakeholders (2013)
- Capacity building activities regarding the functioning and up-scaling of alternative institutional innovations carried out among all stakeholders (2014)

PARTNERS (INTERNATIONAL, NATIONAL AND REGIONAL)

The initial R4D partners in DRYLAND CEREALS (ICRISAT, ICARDA, the Generation Challenge Program, ICAR, AREEO, IRD, CIRAD, INTSORMIL – see Appendix 5 for background information) believe that organizing their work under a single, global CRP will provide numerous benefits, and help to resolve roadblocks that they are unable to resolve individually. These organizations are currently engaged in a number of partnerships spread across the four regions targeted by this CRP (Figure 12). They also recognize that there are many unknowns and that structural and operational issues will certainly require attention as DRYLAND CEREALS is implemented. A streamlined management structure for the CRP is proposed (Figure 13) so that such issues can be quickly addressed, and so that the CRP can respond efficiently to changing circumstances and new opportunities, and make mid-course corrections in a timely fashion. Overall governance, management and coordination of the CRP are described in detail later in the document (see Governance and Management section).

A number of both traditional and entirely new partnerships are envisioned under the auspices of DRYLAND CEREALS, but business not as usual is a critical partnership principal. In general terms, partners in this venture will include: National Agricultural Research and Extension Systems (NARES); Advanced Research Institutions (ARIs) in developing and developed countries; agricultural development NGOs and CSOs; sub-regional and regional organizations; local, national and international private sector agricultural R4D entities; and not least, smallholder famers and well-established farmers' associations in key locations (Table 9).

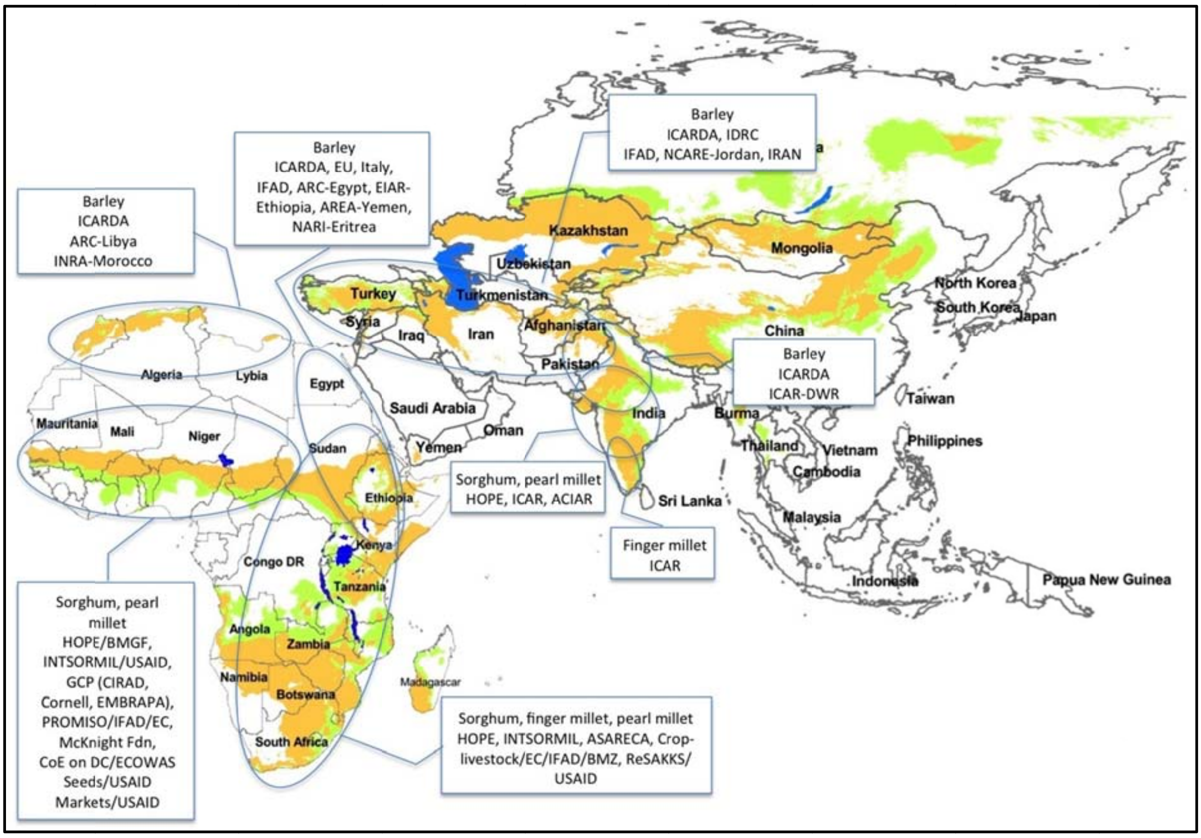

Figure 12. Current DRYLAND CEREALS partnerships

Partners will be brought in based on their comparative advantages, not because it will be "politically correct" to do so. Each will bring resources to the CRP – in many cases on an "in-kind" basis – as well as specialized expertise and their links to networks of other research and development organizations that may contribute indirectly (and on occasion, directly) to our work. When necessary to help ensure the success of DRYLAND CEREALS, partners will be supported with resources from the CRP, and many will participate in capacity strengthening activities carried out as part of individual objectives. The ability to deliver promised outputs in a timely fashion will be a key consideration in the selection of partners (and in their continued participation over time). Partners will operate on an equal footing with one another, must be willing to share information, and will come and go depending on the interests and needs of the partners themselves, and of the CRP.

Partners and their roles were introduced under each Strategic Objective and more details regarding each partner and the specific activities they will undertake in accomplishing each Output are provided in Appendix 4.

Table 9. Role of partners in DRYLAND CEREALS

Output	NARES in Africa & Asia	ARIs	Private Sector	NGOs, CSOs, Farmers Organizations	CGIAR Centers
Strategic Objective 1 – Better targeting of opportunities for technology development and delivery of dryland cereals to smallholder farmers in Africa and Asia					
Output 1.1 Knowledge and priorities for R4D opportunities along the dryland cereals value chain to increase benefits to smallholder farmers, especially women	Conduct data collection for priorities, participate in priority setting, and help identify new opportunities.	Contribute existing databases, based on ongoing and previous project in the target regions. Help in capacity building	Use information to guide new areas of activity. Provide feedback on targets.	Contribute to data collection, and the identification of priorities for crop improvement research	Facilitate data collection and storage/analysis for priorities, participate in priority setting, identify policy changes required
Output 1.2 Knowledge of trade-offs between food and non-food uses of dryland cereal multipurpose varieties and hybrids	Conduct data collection for key non-food uses and sub-sector analyses, and help identify opportunities.	Contribute know-how, data, and analytical tools.	Research into non-food uses of dryland cereals; contribute efforts towards establishing market outlets.	Contribute to data collection and promotion of non-food uses of dryland cereals.	Investigate non-food uses for cereals and facilitate data collection and storage/analysis.
Output 1.3 Evidence for policy and regulations to increase demand and supply of dryland cereal grain and processed products	Conduct data collection for the development of policy briefs and outlook reports. Provide ground-level information.	Provide improved analytical tools and models for ex ante analysis.	Use analysis to guide policy decisions and investment focus.	Contribute to data collection and information on policy and regulation needs.	Facilitate data collection and storage/analysis to help guide policy decisions.
Strategic Objective 2 – Enhancing the availability and use of genetic diversity, genomics and informatics to enhance the efficiency of dryland cereal improvement					
Output 2.1 Dynamic dryland cereal germplasm conservation, exchange and utilization	Identify missing genetic resources and conduct collection missions, and establish phenotyping facilities.	Identify missing genetic resources, support the establishment of phenotyping facilities and integrated breeding platforms, develop genomic tools	Capacity strengthening of breeders interested to develop hybrids (Private Seed companies)	Contribute skills and field facilities for variety and germplasm evaluation	Identify missing genetic resources and conduct collection missions, establish phenotyping facilities and integrated breeding platform, develop genomic tools
Output 2.2. Characterized dryland cereal genetic resources for key traits and future use	Evaluate germplasm sets (core, mini core, reference, TILLING population and FIGS subsets) for key traits in hot spot areas and select useful lines.	Develop new tools, methods and approaches to identify trait specific germplasm, mechanisms and component traits; assist in capacity building	Use new tools/techniques, and selected germplasm for developing high yielding cultivars with wide adaptation	On farm testing and adoption of selected germplasm and high yielding broad based cultivars	Development of germplasm sub sets, precise characterization and evaluation of the germplasm collections, documentation, and knowledge sharing

Output	NARES in Africa & Asia	ARIs	Private Sector	NGOs, CSOs, Farmers Organizations	CGIAR Centers
Output 2.3. Modern genomic and information-based platform for more efficient and integrated breeding	Participate in the implementation of integrated data management systems with a focus on breeding and develop genomic tools (especially for pearl and finger millet)	Technological support for developing new tools and training in development and use of modern technologies	Provide/co-develop cost-effective and high-throughput genomics technologies for the R4D community; utilizing new tools and technologies for product development	Promoting and enhancing adoption of products resulting from the use of new tools.	Identification/development and use of new genetic and genomic resources, , molecular markers ,and modern breeding methodologies to broaden the genetic base for crop improvement and capacity building of partners
Strategic Objective 3 – Developing improved dryland cereal varieties and hybrids for increased yield, quality and adaptation in smallholder farmers' fields					
Output 3.1. High grain and fodder yielding varieties and hybrids with desired end-user quality attributes	Participate in the development, evaluate and disseminate high yielding varieties and hybrids in various production systems	Capacity building (including graduate students) in use of modern breeding methodologies	Development and commercialization of superior cultivars and hybrids	Promotion of superior varieties and hybrids.	Development of improved varieties with a broad genetic base for different production systems; capacity building for partners.
Output 3.2. Varieties and hybrids with better tolerance to heat, drought, salinity and low soil fertility	Development, testing, evaluation and selection of improved varieties under key abiotic stresses	Sources of *Striga* resistance Assistance in developing and capacity building of high-throughput phenotyping and genotyping platforms. Provide capacity building.	Testing and evaluation sites, feedback from using specific sources of germplasm. Commercialization of the proven technologies and superior resilient varieties with yield stabilizing traits	Testing of varieties, feedback on usefulness of specific sources of germplasm. Promotion and adoption of resilient varieties.	Conduct breeding to combine multiple traits into widely-adaptable germplasm. Development of improved germplasm with a broad genetic base, and sharing testing sites for the key abiotic stresses.
Output 3.3. Varieties and hybrids with improved resistance to diseases and pests	Development, evaluation, testing, and selection of improved varieties under key biotic stresses	Assistance in developing and capacity building of high-throughput phenotyping and genotyping platforms. Provide capacity building.	Testing sites, feedback from using specific sources of germplasm. Commercialization of the proven technologies and superior resilient varieties with yield stabilizing traits	Variety evaluations, feedback on usefulness of specific sources of germplasm. Promotion and adoption of resilient varieties.	Conduct breeding to combine multiple traits into widely-adaptable germplasm. Development of improved germplasm with a broad genetic base, and sharing testing sites for the key biotic stresses.

Output	NARES in Africa & Asia	ARIs	Private Sector	NGOs, CSOs, Farmers Organizations	CGIAR Centers
Output 3.4. Varieties and hybrids with enhanced green forage, stover and straw varieties for fodder and other uses	Evaluate, select and adopt elite lines and/or varieties with enhanced green forage, stover and straw quality and other in target environments	Assistance in developing high-throughput phenotyping platforms for breeding purpose.	Testing sites, feedback from using specific sources of germplasm. Development and commercialization of varieties	Promoting varieties in the relevant target environments.	Conduct breeding to combine multiple traits into widely-adaptable germplasm
Output 3.5. Varieties and hybrids with enhanced grain qualities for food, feed and industrial uses	Evaluate, select and adopt elite lines and/or varieties with enhanced grain quality and industrial uses.	Generate information on nutritional quality, effect on chronic diseases, and anti-nutritional and toxic factors.	Testing sites, feedback from using specific sources of germplasm. Development and commercialization of varieties	Promoting varieties in the relevant target environments.	Conduct breeding to combine multiple traits into widely-adaptable germplasm
Strategic Objective 4 – Developing sustainable crop, pest and disease management options to capture genetic gains from improved dryland cereal varieties and hybrids					
Output 4.1. Gender responsive crop management options to optimize crop productivity in smallholder farmer fields	Evaluation and dissemination of gender-responsive sustainable management strategies	Development of new crop management options. Provide capacity building	Commercialization of products and services to enhance crop protection and crop production	Encourage and promote optimal technologies	Develop, evaluate, and share best bet integrated crop management technologies.
Output 4.2. Integrated *Striga*, disease, pest and weed management options to meet the social, environmental and ecological sensitivities of dryland cereals	Identify and prioritize various constraints for developing integrated crop management practices and identify access channels.	Development of new s integrated *Striga*, disease, pest and weed management options.	Commercialization of products and services to enhance crop protection and crop production	Encourage and promote optimal technologies	Develop, evaluate, and optimal integrated crop management technologies.
Strategic Objective 5 – Enhancing effective seed and information systems for better delivery of improved technology packages to smallholder farmers					
Output 5.1. Integrated crop and management technology packages for dryland cereals	Participate in the development, evaluation and dissemination of integrated crop and management technology packages and the identification of access channels.	Development of new technologies and technology packages.	Commercialization of products and services to enhance crop management. Develop options for providing production credit to smallholder dryland cereal farmers	Promote the adoption of optimal technology packages.	Develop, evaluate, and share optimal Integrated crop and management technology packages, assess opportunities for using new communication tools

Output	NARES in Africa & Asia	ARIs	Private Sector	NGOs, CSOs, Farmers Organizations	CGIAR Centers
Output 5.2. Innovations to strengthen seed and input delivery systems for smallholder farmers	Support local, community-based and commercial seed system developments, identify appropriate input dealers	Develop seed and input supply options, assist in establishing local seed and input systems, facilitate local private-sector seed systems	Build up capacity for dryland cereal seed distribution, and possibly production. Develop options for providing production credit to smallholder dryland cereal farmers	Establish capacity for quality seed production, and linkages o seed markets, local seed distribution systems, linking to traditional informal seed systems	Develop seed and input supply options, assist in establishing local seed and input systems, facilitate local private-sector seed systems
Output 5.3. Better communication and knowledge sharing options for improved awareness and use of dryland cereal technologies	Identify technologies, and partners, and domains for developing various knowledge sharing platforms for implementation	Develop and provide crop and other domain-specific knowledge/information	Technology platforms to disseminate knowledge of the identified technologies	Create awareness among farmers about various knowledge sharing platforms available, and facilitate implementation of appropriate knowledge sharing technologies	Anchor various knowledge sharing platforms, validate information, content and promote technologies across geographies
Strategic Objective 6 – Adding post-harvest value and improving market access of dryland cereals to provide smallholder farmers more benefits from dryland cereals					
Output 6.1. Improved storage and processing technologies to reduce post-harvest losses in quantity and quality	Develop capacity for processing business incubation; conduct grain quality evaluations	Food processing research, Engineering research	Contribute experience in processing technology and postharvest handling of dryland cereals.	Organize producers groups of small holder to access better storage and processing technologies. Test business models for small and medium rural and urban grain processing enterprises	Facilitate collaboration across the wide range of actors; set priorities for specific initiatives, and the monitoring; conduct research on storability, and possibly post-harvest handling of grain
Output 6.2. Novel and diverse dryland cereal-based products to stimulate demand for grain	Develop technological interventions to produce various dryland cereal-based food products.	Food processing research, Engineering research	Contribute experience on marketable processed food products from dryland cereals. Contribute efforts towards facilitating purchase form small-holder farmers, based on value chain analyses	Organize producers groups of small holder farmers for market access and increased profitability of production Test business models for small and medium rural and urban grain processing enterprises	Facilitate collaboration across the wide range of actors. Conduct research on novel uses of dryland cereals.

Output	NARES in Africa & Asia	ARIs	Private Sector	NGOs, CSOs, Farmers Organizations	CGIAR Centers
Output 6.3. Institutional innovations to improve linkages between smallholder farmers and markets	Evaluate, advocate and adopt sustainable policies to promote cereal products, and benefit stakeholders	Assist with policy formulation, and capacity building	Promote value chain based agribusiness ventures. Develop options for providing production credit to smallholder dryland cereal farmers	Organize producers groups of small holder farmers for market access and increased profitability of production; train producer groups for increased production, improved profitability and use of modern market information options. Promotion and adoption of inclusive market oriented systems	Develop appropriate innovations and practices for sustainable institutional systems

INDICATIVE LIST OF EXISTING AND POTENTIAL PARTNERS

National Agricultural Research and Extension

Institut National de l'Environnement et Recherche Agricole (INERA), Burkina Faso
Institut d'Economie Rurale (IER), Mali
Institut National de Recherches Agronomiques du Niger (INRAN), Niger
Institut Sénégalais de Recherche Agricole (ISRA), Sénégal
Ethiopian Institute of Agricultural Research (EIAR), Ethiopia
Kenya Agricultural Research Institute (KARI), Kenya
Iran (AREEO)
Marathwada Agricultural University (MAU), India
ARC-Egypt
AREA-Yemen
NARI-Eritrea
NARES in Jordan, Lebanon, Morocco, Algeria, Tunisia, Azerbaijan, Armenia, Georgia, and Nepal Syria Turkey Pakistan Bangladesh
Mahatma Phule Krishi
Vidyapeeth (MPKV), India
Sokoine University of Agriculture, Tanzania
Maseno University, Kenya
Hawassa University, Ethiopia
AMSP, Burkina Faso
UGCPA, Burkina Faso
Haramava University, Ethiopia
Moi University, Kenya
National Bureau of Plant Genetic Resources, ICAR, New Delhi, India
Directorate of Sorghum Research, ICAR, Hyderabad, India
All India Coordinated Pearl Millet Improvement Project, ICAR, Jodhpur, India
All India Coordinated Research Project on Small Millets Improvement, ICAR, Bangalore, India
Directorate of Wheat Research, ICAR, Karnal, India
ITA, Senegal
EISMV, Senegal
CRRA, Mali
INRAB, Burkina Faso
CREAF, Burkina Faso
IRSAT, Burkina Faso
CERRA, Niger
Lake Chad Research Station, Nigeria
University of Maiduguri, Nigeria
SARI, Ghana
NARO, Uganda
Alemaya University, Ethiopia
Axum University, Ethiopia
Hombolo Research Station, Tanzania
Department of Crop Research, Tanzania
IIAM, Mozambique
Medical Research Council, South Africa
University of Free State, South Africa
University of Pretoria, South Africa
College of Agriculture, Botswana
Zari, Zambia
UNZA, Zambia

Advanced Research Institutes

EMBRAPA, Brazil
Cornell University, USA
Scottish Crop Research Institute (SCRI), UK
Australian Center for Plant Functional Genomics, Australia
University of Minnesota, USA
CIRAD, France
IRD, France
University of Abomey-Calavi, Benin
IRSAT, Burkina Faso
Technical University of Munich, Germany
Carlsberg Research, Denmark
Wageningen University, Netherlands
USDA/ARS, USA
JIRCAS, Japan
Queensland Department of Primary Industries & Fisheries, Australia
University of Queensland, Australia
University of Hohenheim, Germany
University of Kassel, Germany

University of Georgia, USA
Kansas State University, USA
Ohio State University, USA
Purdue University, USA
Texas A&M University, USA
West Texas A&M University, USA

CGIAR Centers
CIMMYT
ICARDA
ICRISAT
IFPRI
ILRI
IRRI

Private Sector
aWhere, USA
DigitalGlobe, USA
ABA Malting Plant, Nigeria
Unga Mills, Kenya
Syngenta, Switzerland
DuPont, USA
Assela Malt Factory
Ethiopian Breweries

NGOs, CSOs, Farmer Organizations
Institut Polytechnique Rural, Mali
Coprosem, ULPC
Amedd
Technoserve
Purchase for Progress, WFP
Fuma Gaskya, Niger
IFAD-PPILDA, Niger
IFAD-PDRD, Burkina Faso
IFAD-CBARDP, Nigeria
Farm Radio International, Canada
AGRA
Helen Keller Institute
Africa Harvest, Kenya
Association des Organisations Professionnelles Paysannes (AOPP), Mali
Union Locale des Producteurs de Cereales (ULPC), Mali
ASEDES, Mali
Mooriben, Niger
Minim Sông Pânga, Burkina Faso
Union de Groupement pour la commercialisation des Produits Agricole, Boucle du Mouhoun (UGCPA/BM), Burkina Faso

GENDER STRATEGY

Women produce over half the food in many developing countries, bear most responsibility for household food security, and contribute to household wellbeing through their income generating activities. Women play a critical role in agriculture, accounting for about 70-80% of household food production in Sub-Saharan Africa and 65% in Asia (FAO, 1994). Yet, women usually have more limited access to resources and opportunities and their productivity remains low relative to their potential. Programs and projects that ignore gender specific barriers to resources, opportunities, and benefits have a risk of excluding a large proportion of farmers (who are women) and the farming community. Analyzing quantitative and qualitative information during the implementation of DRYLAND CEREALS will improve our understanding of the specific roles of men and women in dryland farming systems, especially mixed crop-livestock systems.

Building on the guidelines developed by the Program on Participatory Research and Gender Analysis (PRGA) and the Mainstreaming Framework from the Gender Scoping Study done by ICRW, the scientists involved in DRYLAND CEREALS will work collectively to ensure that all objectives, activities and outputs are gender responsive. Key considerations will include recognition of the role of gender in maintaining and utilizing dryland cereal crops, women farmer-led research and the need for participatory and gender-responsive approaches to the problems of poverty, food security and sustainability.

As a crosscutting issue, gender will be integrated in each of our Strategic Objectives and at all stages of the project cycle. Gender analyses will be guided by standard gender analysis frameworks, including the Harvard and the World Bank tool kit (Feldstein et al., 1994), and by female empowerment frameworks. These will be based on analysis and understanding of gender roles along the whole value chain, using and generating new gender-disaggregated data that will inform the future directions of DRYLAND CEREALS.

Women in dryland areas tend to be disadvantaged economically, less empowered in decision-making, and more prone to malnutrition than men. These disadvantages impact their children as well. Thus women, and through them the young children that depend on them, will receive special attention.

Women's traditional roles in dryland cereal cultivation differ across countries and ethnic groups. In many cultures, women's responsibilities are primarily post-harvest management (transport, threshing, cleaning and storage) and processing, for both home consumption and local marketing. In some areas, particularly in WCA, women are also deeply involved in the production segment of the value chain. They manage their own production fields, providing both incomes for themselves and a food security reserve for their children. They are often active in farmer organizations. Specific efforts will be made to identify channels and mechanisms for reaching women to share modern technologies and build their capacities.

As DRYLAND CEREALS is implemented, gender disaggregated roles will be explicitly addressed in all Objectives, especially on the following:

- Gender-differentiated data collection, including for baselines and impact assessments, will take into account gender issues to capture differing roles and benefits for men and women;
- Capacity strengthening and technical training that includes women in equitable numbers will capture gender needs, targets, achievements, and participation (e.g. in farmer field days, training of trainers, and workshops); and
- Technologies will be developed that deliver particular benefits to women (e.g. reducing drudgery, but even more importantly opening opportunities for value-adding post-harvest processing and food preparation operations that are typically carried out by women).

At its simplest, our gender analysis will be asking questions about the differences between men’s and women’s activities, roles, and resources to identify their developmental needs. Assessing these differences makes it possible to determine men’s and women’s constraints and opportunities within the dryland cereals farming systems. This will ensure the provision of agricultural products and services that are needed by men and women farmers and are appropriate to their circumstances.

Gender and Strategic Objective 1
Because women and men farmers usually have different and complementary roles in crop management, from production to consumption, they have different needs, priorities and knowledge related to traits and crops that are taken into account by the households when adopting new technologies. To increase adoption rates of improved varieties, it is important that the gender-differentiated needs of all farmers involved along the food chain inform breeding strategies.

Strategic Objective 1 will thus mainstream gender-disaggregated data collection and analyses on the roles of women and men in dryland cereal value chains. Gender-sensitive data collection methods like women enumerators will be employed to elicit information on gender sensitive issues. Special training programs in the area of skill enhancement, processing, value addition, and small agribusiness entrepreneurship will be conducted for women empowerment. Gender perceptions on the quality attributes of the grain and fodder and tradeoff between food and non-food uses of the grain will be assessed. The institutional arrangement for active participation of women groups from seed to final product in the value chain will be analyzed. The economic viability of different options of formal linking of smallholder women groups to various service providers will be analyzed. Welfare implications of drudgery reduction technologies will be evaluated for scaling up.

Gender and Strategic Objective 2
Strategic Objective 2 will focus on improving the range of genetic variation and the selection protocols used by DRYLAND CEREAL breeding programs to develop improved cultivars that can create market opportunities to benefit women, particularly opportunities that lead to empowerment and improved livelihoods. Target traits relating to nutrition and food security are particularly relevant to women, as are those relating to improving feed and fodder quantity and quality, because women often care for household livestock. Improved processing technologies that make it easier for women to process food for home consumption, and to process it in larger quantities for storage and the market, can help reduce drudgery and the workload handled by women. Therefore, in large part trait-specific research in this CRP will focus on:

- Traits that are critical to food security, improved nutrition and reduced drudgery for women and children;
- Abiotic stress tolerance and biotic stress resistance that enhance food security by improving stability of production;
- Improved crop establishment characteristics that enhance food security; and
- Enhanced food processing and storage characteristics and nutritional quality.

Gender and Strategic Objective 3
Focusing on increasing “whole plant value” for primary producers of these crops, this Strategic Objective will assess crop value for the entire farm family, especially in situations where the crop serves as a staple food for much of the year, and where family labor is a the key source of labor for cultivation and processing. Achieving such a balance of criteria for evaluating, creating and disseminating new varieties of dryland cereals requires:

- Improvements in the gender knowledge and analysis skills of the scientists and other partners involved;
- Commitment of partners along the research continuum to act on gender-specific client needs, and to develop technology options with benefits to the entire farm family;

- Commitment of research and development partners to communicate successes and failures of specific actions in this direction; and
- Effective increases in whole plant value and/or productivity of dryland cereals.

To facilitate these changes, cereal improvement teams in the different regions are committed to:

- Including women farmers as members of the steering committees of projects;
- Assessing the roles of women in various crop management and processing operations in target regions;
- Supporting women self-help groups in target regions, especially in the context of cereal processing and commercialization;
- Inclusion of women in decision making, especially on the choice of varieties;
- Establish specific variety trials for women, adapted to enable women's participation;
- Communication and training targeted specifically for women and women's associations, avoiding pitfalls of indirect communication through husbands and giving less attention to women's specific conditions;
- Feedback sessions, specifically for and with women, in which results of experimentation are discussed;
- Training women farmer groups to adopt mechanization to reduce drudgery and labor in agricultural operations and enterprise skills development; and
- Making information on nutritional advantages and innovations readily available to all members of households.

Gender and Strategic Objective 4

Gender and crop management tasks – In most parts of the world, men and women tend to work at different tasks. Although many tasks may be viewed as exclusively women's or men's, in practice the divisions are blurred, and both men and women are involved. That women throughout Africa tend to provide more labor for agriculture than men – and almost always provide more total labor – has implications for technology adoption. To the extent that tasks vary by gender and the value placed on women's time often lower, farmers may be more inclined to adopt technologies that save men's time. This dynamic will be analyzed as part of this Objective, in collaboration with Strategic Objective 1.

Gender and soil fertility management – Women, especially if they are the main providers of staple foods crops, are particularly affected by declining soil fertility. They often have limited or no access to chemical fertilizers, but many alternatives to inorganic fertilizers are available (animal manure, legumes, living mulch, crop rotations, and conservation tillage to name a few). Involving women in soil fertility management innovations is a key approach under this Objective and collection of gender-disaggregated data for targeting promotion activities on fertilizer will facilitate the impact of interventions from a gender perspective.

Gender and crop protection interventions – Twenty to forty percent of the world's potential crop production is lost annually to weeds, pests, and diseases and crop protection strategies have changed with the intensification of agriculture. Pesticides can increase agricultural productivity, but when handled improperly, they can be toxic to human. Key gender-related issues include:

- Gender and knowledge of pesticide risks – Compared to men, women are less informed about safe pesticide practices and dangerous side effects, and have greater difficulty in obtaining protective gear.
- Pesticide exposure – The limited access to information about safe pesticide use imperils human health and poses environmental hazard, and given that women and children are often

involved in applying pesticides when they are used, special efforts must be made to create awareness and minimize associated risks.

Gender, knowledge and information differences – Men and women can accumulate very distinct and rich sets of agricultural knowledge and skills as a result of gender divisions in the tasks they undertake, such as seed management and conservation and pest and disease management. In making decisions about their livelihoods, men and women have different perceptions of what is important. Men and women base their decisions on information from different sources. The unequal power relationships between rich and poor, men and women, must be understood to achieve equitable development and full participation of women. Crop management interventions must therefore be developed based on a comprehensive understanding of the differing needs that women and men have relative to improving their situations.

Thus, a number of gender-specific activities will be undertaken relative to crop management interventions. Appropriate gender participation targets will be established with our partners and we will invest in enhanced female leadership and capacity within local partner implementing agencies.

Gender and Strategic Objective 5

Women are often the seed guardians in rural communities and households, and play a critical role in agricultural development. The traditional role of women as seed selectors and preservers is widely recognized. The local seed system analysis provided highlights of gender roles in on-farm seed production and management, and place women in a key position for participatory variety selection and seed production. Women farmers will be targeted for accessing seed of new dryland cereal varieties and women entrepreneurs encouraged to form alternative farmer-based seed production and marketing enterprises envisaged within the seed initiative. This could be linked to on-farm processing and value addition of dryland cereals food products operated by women.

Gender and Strategic Objective 6

While dryland cereal crops tend to be considered food staples in most situations, and not cash crops, it is often women who generate income from marketing products processed or derived from them: traditional malted products, small ruminants or poultry fed on dryland cereal by-products – straw, bran etc., or processed local foods, e.g. “fura” in Nigeria. Identifying opportunities for improving these value chains will help increase women’s income. Women dominate the processing sector for dryland cereals, both in the home, and for traditional food marketing. However this “informal” sector could benefit from technologies that enhance quality, business management skills, capacity for achieving economies of scale, and effective marketing. Thus, we will investigate business models for spreading the use of threshers, mechanical “dehullers” or decorticators, as well as small-scale flour mills, in a manner that women can benefit from new business opportunities, not only from the reduction of drudgery. Improving the availability of processed dryland cereal products in cities will also benefit poor urban women, who spend a lot of time preparing food for the family. Indeed, the labor for processing cereals into food for household consumption tends to be fully women’s responsibility.

The long-term health effects of malnutrition are most serious for young children and for expecting and nursing mothers. Strategic Objective 6 will therefore focus much of its attention on these vulnerable groups, but will also address the general nutrition needs of others. To this end, we will adopt gender analysis and participatory methodologies that reveal the needs and preferences of women and men (differentiated by age) in relation to nutritionally enhanced varieties. Women and men have different nutritional needs at different stages in life, and these need to be taken into account to effectively enhance nutritional health in the households.

Malnutrition is related to food availability, access and distribution. Understanding the social dynamics regulating the access of different individuals to food (at the community and intra-household levels), or to the resources needed to purchase it, can support a more equal distribution of healthy and nutritious food. Social and gender analysis can provide insights into these community and intra-household dynamics through in-depth qualitative research. Given their roles as food providers, women (both in rural and urban areas) will be involved in initiatives to increase awareness about the nutritional value of specific crops, and best methods for improving cereal storage and for preserving or improving nutritional properties while cooking. Men will be involved along with the women in these initiatives to ensure agreement at household level regarding food patterns and priorities. Men and women will be sensitized about the existence of value-added traditional and alternative food products.

PROGRAM INNOVATIONS

In addition to doing business differently, the business we will be doing is itself different. We believe that by combining the creative talents of a wider range of partners oriented towards a shared vision and set of strategic objectives will lead to new innovations in DRYLAND CEREALS R4D.

We believe one major innovation is inherent in the CRP idea itself – that we will be more effective in supporting smallholder dryland cereal farmers by approaching them as a cohesive entity, with a common message and new ways of working together. We will be able to present a unified front regarding the importance of dryland crops and speak with a much stronger voice to policymakers in developing countries, and negotiate more successfully with possible investors. We will also be able to more effectively capitalize on new tools and methods for improving the efficiency of research done on behalf of the world's poorest and most vulnerable smallholder producers and urban dwellers – those living in dryland areas. Some specific examples of what we believe to be the major innovations include the following.

Whole genome sequencing of the dryland cereals
The state of knowledge and genomic resource development in the dryland cereals is/has been uneven, and the work done in this area going forward will necessarily vary. Because of its relatively small genome, tremendous genetic diversity, and the availability of a powerful suite of analytical tools, sorghum has become an important species for comparative grass genomics and a source of beneficial genes for agriculture.

Chief among all public resources for sorghum functional genomics is the aligned sorghum genome sequence, which has approximately 30,000 genes (Paterson et al., 2009). With this resource at hand, rapid fine-mapping to identify the genes underlying Quantitative Trait Loci (QTLs) is rapidly becoming possible. Although inconceivable a few years back, cost effective and highly efficient next generation sequencing (NGS) technologies, coupled with the availability of a reference genome sequence of sorghum, is paving the way for "genotyping-by-sequencing" platforms and, more importantly, producing aligned genomic sequence of global germplasm collections. New Generation Sequencing (NGS) will also permit genome-wide scanning for association mapping of all genomic regions contributing to control of economically important traits, overcoming the inherent limitations of current "candidate-gene" approaches, and permit genome-wide selection to reduce the time required per unit of genetic gain from breeding programs.

The advent of NGS technologies is also accelerating the development of genomics resources in other dryland cereals and their relatives. The International Barley Sequencing Consortium is working to physically map and sequence the barley gene space, with the near-term need being the identification of all genes, including their regulatory regions, and the longer-term goal of an ordered and anchored physical map to accelerate crop improvement and pave the way for whole genome sequencing (Schulte et al. 2009).

Developments and innovation in DNA sequencing technology and bioinformatics are changing the landscape both in terms of cost and efficiency. A very exciting development in this arena is single-molecule real-time DNA sequencing (www.pacificbiosciences.com). Proponents of this approach suggest that a genome as big as our own could be sequenced in under an hour at the cost of hundreds of dollars rather than millions. Thus, proposing to sequence all dryland cereals and their accessions in germplasm collections is not beyond the realm of possibility today. Clearly, partnering with ARIs and the private sector will be a key to this endeavor.

Genetic resources, phenotypic databases, and geospatial information
Large numbers of accessions are present in different gene banks for dryland cereals, so NGS technologies should enable re-sequencing of thousands of accessions for a given species. Discussions are underway for re-sequencing numerous barley accessions in the genebank at IPK-Gatersleben,

Germany. In the case of sorghum, several hundred genotypes are being re-sequenced in the USA. Re-sequencing of accessions should provide a better overview on genome variation present in germplasm collections that will maximize the use of natural variation in crop breeding.

To fully capitalize on these extraordinary genomics resources, germplasm collections will need to be more systematically and precisely phenotyped. Logically, traits that are key to crop adaptation to the abiotic and biotic constraints prevailing in dryland farming systems will be given high priority, as will those useful in defining and promoting the most sustainable modes of utilization of these crops in the major dryland agro-ecological/market environments. Ideally, phenotypic data should be stored in databases that also contain passport and characterization data that are actively curated. Cross-compatibility across species would be desirable, especially for the orphan crops where comparative genomics will continue to be the most readily available option for at least the medium term. Bioversity has recently developed more detailed lists of characterization data sets for *ex-situ* germplasm collections (e.g. for sorghum, pearl millet and finger millet).

The analysis of dryland traits – drought, heat, and salinity tolerance – in these very tolerant crops is a key research domain that will also have implications for the improvement of these traits in the other cereals. Biotechnological tools such as high throughput QTL mapping, association mapping, and marker-assisted backcrossing to developed near-isogenic stocks coupled with physiological trait dissection (a thorough dissection and understanding of critical mechanisms) will allow the study of the tolerance factors across these dryland cereal species. Traits analyzed and understood in one species (e.g. stay green in sorghum) will also be analyzed in the other dryland species. Still another opportunity that should be seized is the implementation of large-scale phenomics platforms to match the power of genomic level genotypes to address the genotype to phenotype connection at the level of crop breeding and collection germplasm.

Crop simulation modeling to predict the value of a given trait on yield across locations and years, which in turn, provides guidance on promising breeding targets will also be explored. This approach would allow more targeted breeding and turn the adversity of GxE interaction into a great opportunity to better understand the interaction of specific plant development mechanisms and the environment. There is an exciting opportunity to enlist eco-physiology to fit particular genotypes to particular environments.

Integrating breeding and marker-based technologies

The use of molecular markers in the breeding process is now well established and has proven its effectiveness and efficiency on major species, especially in the private sector (Collard and Mackill, 2008; Tester and Langridge, 2010). Marker-based quality control at the key steps of a breeding scheme is critical as it allows certification of the material that is being characterized for several years and to make the most of the resources allocated to a breeding program. Marker-assisted backcrossing of monogenic traits is one of the simplest applications of molecular markers and has an immediate and unquestionable added value in terms of time efficiency and the quality of the final product/variety.

With the development of cost effective and high-throughput genotyping and novel statistical tools, it is now becoming feasible to model and predict phenotypes based on an individual's whole-genome genotype. Plant selection based solely on whole-genome genotypes rather than phenotypes – a process termed "genomic selection" (GS) – allows breeders to significantly increase genetic gains per unit of time. Other designs, such as marker-assisted recurrent selection, also allow increased genetic gains by enabling a deeper exploration of allelic combinations provided by crosses. This should facilitate the breaking of some 'trait antagonisms' that classical breeding has failed to overcome so far. The spread of these technologies and methodologies is critical for improving breeding efficiency and capacity.

The development of innovative, proof-of-concept breeding projects in partnership with NARES, CGIAR centers and ARIs will contribute to major advances in genetic gains, enhanced capacity in national programs, and the emergence of a new generation of breeders that will regularly use marker-based technologies in their work.

In order to help boost the potential impact of these projects and of other breeding and molecular breeding initiatives of DRYLAND CEREALS, the *Integrated Breeding Platform* (IBP) being developed under the auspices of the Generation Challenge Program, will provide a centralized and functional portal to store and retrieve information, to access analytical and data management tools, and high-throughput genotyping services. Such a platform will enable breeding programs in the public and private sector to design and efficiently perform marker-assisted breeding and accelerate variety development for developing countries.

Tapping heterosis to boost yields

Hybrids will be targeted to produce more stable and higher yields in extreme stress environments, producing more when it is needed most. Pearl millet in India and for the Sahel; barley for expanses of the steppe; sorghum for residual moisture conditions in peninsular India; and photoperiod sensitive sorghums adapted to low phosphorus conditions in West Africa are all examples of how hybrids can serve smallholders in the disadvantaged dryland regions.

Hybrids will provide the opportunity to trigger collaboration among a wide range of actors. Farmers, researchers from a range of disciplines, development partners, communication providers, input providers, credit providers, merchants and grain processors can act in concerted manner in given target regions – assuming appropriate incentives are in place – to turn high cereal prices into benefits for smallholder farmers. Mechanisms for interaction and platforms for local innovation will need to be created to facilitate this process.

Efficient production of multi-purpose varieties

Work recently done on pearl millet may represent one of the first proof-of-concept experiments for genetic gains in food-feed traits achieved through conscious, targeted selection, namely using recurrent selection and marker-assisted breeding with the aim of producing superior dual-purpose varieties. Within two recurrent selection cycles important fodder quality traits increased by 15%. The improvement in stover fodder quality came at no penalty for grain or stover yield (Bidinger et al., 2009). These results suggest that new hybrids can be developed with concomitant improvements in grain and stover traits (Nepolean et al., 2009). Given the substantial and largely untapped genetic variability present for feed/fodder quality traits in all species included under this CRP, and the ready availability of high-throughput, breeder-friendly selection technologies (NIRS), significant genetic progress for fodder quality and the development of successful dual-purpose cultivars adapted to dryland farming systems are likely to occur rapidly.

Improving shelf life of dryland cereal products

Rapid rancidification of pearl millet flour (within 7-10 days after milling) is a major barrier in the commercialization of pearl millet flour-based products (Nantanga et al., 2008). This is relatively less of a problem in barley and sorghum, and there appear to be no studies on finger millet. Fortunately, there are processing technologies under development that can enhance the shelf life to several months. A new method that involves moist heating of the grain followed by drying to about 10-12% moisture and decortication appears to increase the shelf life of sorghum flour for up to 8-10 months, and pearl millet flour for up to 3-4 months. This technology could produce a breakthrough in the commercialization if it proves feasible for large-scale application. Furthermore, research suggests that there is genetic variation for rancidity associated traits and for the tolerance of pearl millet flour to storage (Chugh and Kumar, 2004). Thus, opportunities exist to make improvements in shelf life from an approach that explores a crop improvement angle in combination with an assessment of processing technologies.

INTERACTIONS WITH OTHER CRPS

DRYLAND CEREALS will partner with several other CRPs, providing outputs, drawing inputs and engaging in joint activities with them (Table 10). The connection points are evident from the activities and outputs in our three Strategic Objectives. DRYLAND CEREALS will contribute varieties and management practices for integrated agricultural systems for the drylands (under CRP 1.1). CRP 1.1 will provide opportunities to evaluate and promote improved varieties, agronomic methods and seed systems in the targeted dryland systems. Enhanced incomes for smallholder farmers will be catalyzed through CRP 2 via science-based policy advice and identification of new market opportunities. Dryland Cereals will adopt multi-dimensional crop improvement approaches addressing multiple traits at the same time, including feed and fodder value of stovers and other by-products. Feed and fodder improvement will be done in close collaboration with CRP 3.7 and its feed- and fodder-related activities. DRYLAND CEREALS research will have important synergistic relationships with crop CRP 3.1 (WHEAT), CRP 3.2 (MAIZE), CRP 3.3 (GRiSP) and CRP 3.5 (Grain Legumes). Interactions with CRP 5 will contribute to formulating solutions to water scarcity and ecosystem degradation, and with CRP 7 aimed at enhancing agricultural productivity in the context of climate change. As dryland cereals are among the most adapted cereals for harsh environments, CRP 5 will be able to evaluate their role in improving resource use. CRP 7 will provide models of possible changes in dryland areas so that better targeting of crops and varieties can be achieved. DRYLAND CEREALS will provide crop parameters for use in improving crop models used in climate change predictions.

Farmers living in drought-prone dryland environments need risk-mitigating production options, such as highly stress-resistant varieties and management systems that are resilient to such shocks. DRYLAND CEREALS, working jointly with CRP 1.1, CRP 2 and CRP 5 will deliver this combination of synergistic innovations. The dependence of improved varieties on fertile soils to express their genetic potential will be addressed through joint work with CRP 1.1 on crop management strategies that the poor can afford. This joint work will cover the entire process cycle, including strategy development and planning, knowledge sharing, and joint priority setting.

In general terms, linkages between DRYLAND CEREALS and nearly all the others will be facilitated and reinforced by the fact that all CRPs are characterized by multi-center participation – scientists and managers from different centers will work together under different CRP umbrellas, conducting joint research, planning CRP activities, setting priorities together, and working with many of the same non-CG partners. This collaboration will go far towards ensuring that interdependence and shared accountability are not only recognized, but also embraced by CRP participants as part of a new and better way of doing business.

Table 10. Envisioned linkages and collaboration between DRYLAND CEREALS and other CRPs

CGIAR Research Program	Outputs from DRYLAND CEREALS	Inputs to DRYLAND CEREALS	Joint Actions with DRYLAND CEREALS
CRP 1.1 Integrated Agricultural Production Systems for Dry Areas	Improved dryland cereal germplasm, production and processing technologies, and information on seed and input systems, value chains, and market access.	Prioritization and targeting of dryland cereal-based components in dryland production systems.	(1) Characterizing and cataloging different farming systems and constraints to production in target agro-ecologies to understand the varietal needs for dryland cereals (2) Modeling and evaluating cropping options for boosting productivity of farming systems (3) Developing appropriate cereal varieties and plant types suitable for intercropping in rainfed and irrigated production systems (4) Developing nutrient-use efficient varieties with resistance/tolerance to abiotic and biotic stresses (5) Generating and evaluating appropriate integrated crop management practices to enhance cereal productivity in different cropping systems (6) Upgrading farmers' skills and knowledge on improved production technologies for cereals in different cropping systems
CRP 2 Policies, Institutions, and Markets to Strengthen Assets and Agricultural Incomes for the Poor	Value-added dryland cereal varieties, information on productivity, value chains, market access, gender issues, and dryland cereal-based technologies.	Foresight on policy and market environments for smallholder dryland cereal production systems to be profitable. Methods for value chain analysis. Trend analysis and scenarios for poverty, markets, and risk. Models and tools for impact assessment.	(1) Identifying deficiencies in existing marketing systems of dryland cereals and devise mitigation strategies (2) Developing advocacy briefs that promote farmer-friendly marketing infrastructure and protocols for dryland cereals (3) Identifying and standardizing quality control mechanisms for cereals and train farmers and buyers in quality control and monitoring (4) Promoting the interface between food processors and cereals growers and train stakeholders along all key points of the value chain (5) Identifying policy interventions for effective seed systems for ensuring availability of quality seed of dryland cereal varieties to farmers at affordable price (6) Strengthening the skills of partners for gender-sensitive, interdisciplinary, inter-institutional and multiple-stakeholder problem solving

CGIAR Research Program	Outputs from DRYLAND CEREALS	Inputs to DRYLAND CEREALS	Joint Actions with DRYLAND CEREALS
CRP 3.1 WHEAT **CRP 3.2 MAIZE** **CRP 3.3 GRiSP: A Global Rice Science Partnership**	Genetic/genomic/phenotypic information in dryland cereals on traits common with wheat, maize and rice; varieties and production technologies suitable for cereal-legume and crop-livestock systems, and dryland cereal-based information, and technology.	Genetic/genomic/phenotypic information in wheat, maize and rice on traits common with dryland cereals	(1) Exchange information on breeding methodologies as well as the phenotypic and genotypic understanding of abiotic and biotic stresses (2) Establishment of the integrated breeding platform
CRP 3.5 Grain Legumes	Appropriate dryland cereal varieties for the respective mixed cereal-legume intercropping systems; genetic/genomic/phenotypic information in dryland cereals on traits common with grain legumes	Genetic/genomic/phenotypic information in grain legumes on traits common with dryland cereals	(1) Exchange information on breeding methodologies as well as the phenotypic and genotypic understanding of abiotic and biotic stresses (2) Cereal-legume feed/fodder mixtures appropriate for smallholder farmers (3) Establishment of the integrated breeding platform
CRP 3.7 Sustainable Staple Food Productivity Increase for Global Food Security: Livestock and Fish	Strategic research on feed/fodder quality, improved cereal varieties with better fodder quality traits and development of integrated crop management practices for ensuring high quality of cereal fodder	Phenotyping of dryland cereal varieties to determine feed/fodder quality and processing options	(1) Foster enhanced awareness and significance of fodder among farmers and livestock and livestock-product producers (2) Optimize sorghum and millet cultivar types for crop-livestock systems (3) Identify and facilitate entry of sorghum and millet stovers into fodder/feed value chains
CRP 4 Agriculture for Improved Nutrition and Health	Strategic research on enhancing the nutritional value of dryland cereals, nutritionally enhanced germplasm, breeding approaches and functional markers.	Targeting, advocacy, promotion of nutritionally enhanced dryland cereals, and insights on the interaction of gender and nutrition and health.	(1) Priority setting for new traits (2) Developing cereal varieties with better nutritional quality and consumer appeal and agronomic practices for improved product quality (3) Developing new products and processing methods for enhanced nutritional value of dryland cereals (4) Studying bioavailability, bio-efficacy and bio-effectiveness of nutrients from cereals and their value-added products (5) Advocating the consumption of dryland cereals and their value added products

CGIAR Research Program	Outputs from DRYLAND CEREALS	Inputs to DRYLAND CEREALS	Joint Actions with DRYLAND CEREALS
CRP 5 Durable Solutions for Water Scarcity and Land Degradation	Information on water, land, and ecosystem information with changes in dryland cereal-based technology evolution.	Best-bet practices for both rainfed systems and irrigated systems where dryland cereals are cultivated in mixed systems or as crop rotations.	(1) Contributing improved varieties with better water and nutrient use efficiency (2) Increasing system productivity through incorporation of dryland cereals in systems (3) Scaling up of findings to the landscape level
CRP 7 Climate Change, Agriculture and Food Security	Improved dryland cereal varieties and dryland cereal-based technologies to be tested for resiliency to the impacts of climate change.	Strategic foresight on the potential impact of climate change on the patterns of biotic and abiotic stresses and adaptation of dryland cereals.	(1) Providing improved dryland cereal varieties which are resilient to the impacts of climate changes (2) Developing varieties with tolerance to drought, heat, and salinity stresses (3) Helping to disseminate the most appropriate climate-ready varieties and management and minimizing the effects of climate variability on dryland cereal productivity

Management Arrangements for Implementation

We have based the governance and management of DRYLAND CEREALS on the principles outlined in the CGIAR Strategy and Results Framework. We believe that effective management of the research will require a significant investment of time by all partners, and especially by the individuals appointed as the DRYLAND CEREALS Director and the Strategic Objective Coordinators. Therefore, we have elected to maintain a minimal Research Management Team that will have the ability to interact often enough for effective management of research progress, especially during the initial few years of the CRP. We recognize that the proposed management structure (Figure 13) may require alterations as the CRP develops, both in terms of membership, responsibilities and the configuration itself. Such possibilities will be continually evaluated and changes implemented as required.

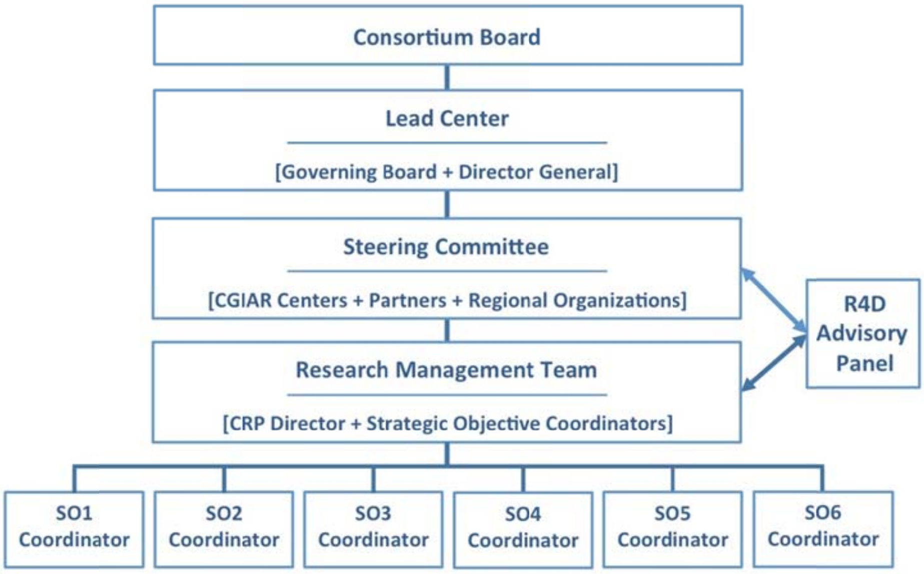

Figure 13. DRYLAND CEREALS Governance and Management Structure

Roles and Responsibilities

As with all CRPs, the **Lead Center** (in this case, ICRISAT) will sign a Program Implementation Agreement (PIA) with the Consortium of International Agricultural Research Centers for implementation of the CRP. The Lead Center, represented by its Governing Board and Director General, will be responsible for the overall performance of DRYLAND CEREALS by providing a clear vision, direction, priorities and focus through an inclusive, consultative and transparent partnership process. Participant Program Agreements will be signed with all key participants according to Consortium procedures and policies.

The **Governing Board of ICRISAT** will have the fiduciary and legal responsibility and accountability for the implementation of the CRP. It will monitor management and implementation, including the performance of the DRYLAND CEREALS Director, Steering Committee and Research Management Team. The governance and/or management entities of the other partners will be expected to provide similar oversight of their respective institute's involvement in DRYLAND CEREALS. This would include ensuring that their institution's policies, vision and mission are in agreement with the CRP, that DRYLAND CEREALS is appropriately reflected in their strategic plans, and that their institution assumes fiduciary and legal responsibilities and accountabilities for implementing the agreed research agenda of the CRP.

The **Director General of ICRISAT** and other **CGIAR Partner Director Generals** will work together to assure the success of DRYLAND CEREALS. Specifically, they will:

- Ensure full implementation of the CRP, including the effective integration of existing and new bilateral projects,
- Assign required staff to the DRYLAND CEREALS management committees/teams,
- Appoint and empower Strategic Objective Coordinators and provide required support, and
- Ensure that performance contracts are successfully managed, including the management of risks.

Overall guidance of DRYLAND CEREALS will be by a **Steering Committee (SC)** that will be chaired by the Director General (or his/her designate) of the Lead Center. Membership of the SC will include the top leaders (or their designates) of major partners – including regional/sub-regional organizations, IARCs, NARES, ARIs and private sector organizations participating in DRYLAND CEREALS. The aim is for the SC to limit its total membership to no more than 12 individuals. The DRYLAND CEREALS Director will serve as the secretary to the SC. The Committee will be responsible for:

- Overall strategic direction of DRYLAND CEREALS;
- Monitoring overall progress across the CRP;
- Advising on mechanisms to enhance operations;
- Building and strengthening strategic alliances with partners;
- Deciding on suggested resource allocations across DRYLAND CEREALS R4D programs and partners; and
- Establishing guidelines for conflict resolution.

The SC will meet face-to-face at least once per year, with at least one additional meeting conducted electronically. It would be desirable if all decisions reflect a consensus among the SC members, but if necessary a simple majority vote will be followed.

To ensure effective management, a **Research Management Team (RMT)** will be chaired by the DRYLAND CEREALS Director and will include the six Strategic Objective Coordinators (see below) plus appropriate research directors from key partners who are not represented by a Strategic Objective Coordinator. The RMT will be primarily responsible for the overall monitoring of research outputs, human resources and finances of the CRP. In the spirit of streamlining management, we propose to limit initial RMT membership to the minimum necessary for representing core DRYLAND CEREALS activities, but allow the RMT to request other CRP staff to participate in its meetings as required. We believe the RMT will require at least monthly meetings during the initial stages of the CRP. Many of these will be conducted electronically, but the RMT would plan to meet face-to-face at least quarterly. The RMT will develop annual research plans and other planning tools as requested by the SC, for the SC's review and approval. The RMT will also request and receive advice from the members of a **R4D Advisory Panel**. All such interactions will be properly recorded and made available to the SC.

The DRYLAND CEREALS Director will be internationally recruited by the Lead Center in consensus with the SC. The Director will lead the CRP's R4D agenda, in consultation with the SC Chair and the RMT. This position will require a full-time commitment and be compensated accordingly; she/he will be covered by the policies of the Lead Center. The SC Chair will oversee the recruitment, approve the Terms of Reference for, and annually evaluate the performance of the DRYLAND CEREALS Director, all in consensus with the SC. The Director will lead the CRP's resource mobilization efforts, partner/donor relations, and ensure timely and high-quality reporting of program activities and progress to the SC and the Consortium Board, through the SC Chair. The Director will also serve as the public representative of DRYLAND CEREALS, working closely with the SC Chair to ensure that the

CRP maintains a high and positive profile with investors and the public. The Director will organize SC, RMT and other meetings and reviews for DRYLAND CEREALS, chairing such meetings where required. The Lead Center will provide an appropriate level of administrative staff to support the functions of the Director.

DRYLAND CEREALS is structured into six Strategic Objectives, each of which will be coordinated by a **Strategic Objective Coordinator**, who will be at least a quarter-time appointment of a scientist and who will continue to be affiliated with their home institution, with the agreement of the institution. It is expected that ICARDA and ICRISAT will host at least one coordinator each, with efforts made to have partner and regional representation across the Strategic Objective Coordinators. Partners will nominate the Coordinators, with appointments being made by consensus of the SC. The Coordinators will ensure that activities for delivering agreed outputs within each region are effectively implemented, coordinated, and monitored/assessed. Coordinators will also maintain close relationships with the DRYLAND CEREALS Director, participating in all RMT meetings, as well as with other Coordinators, relevant partners, donors and stakeholders involved in the CRP.

A **R4D Advisory Panel** will provide a channel for input and advice on DRYLAND CEREALS strategic and implementation issues. The panel will interact primarily with the RMT, but will also have opportunities to provide input/feedback directly to the SC. Given the complex and evolving nature of DRYLAND CEREALS, we propose to appoint a "pool" of scientific and development advisors from a range of institutions/organizations and with a range of expertise. Nominations will be received from all CRP stakeholders by the RMT, which will then make a recommendation to the SC for a consensus approval. These experts will be assembled to provide independent guidance on strategic planning, new R4D opportunities and research progress across the DRYLAND CEREALS agenda. We expect to appoint an initial pool of 6-10 advisors on 1-3 year appointments. Because of the difficulty to organize for all advisors to attend all CRP meetings, we will seek to have at least two advisors present at all physical meetings of the RMT and CRP. One or more advisors may also be requested to participate (usually electronically) in the semi-annual and/or annual SC meetings. All such interactions will be formally recorded and responses documented by the SC or RMT.

Dispute resolution among DRYLAND CEREALS partners or with external parties will be handled, if within the domain of R4D (including partnerships), according to policies established by the RMT. If disputes fall in the domain of institutional and legal responsibilities, the SC will resolve them in accordance with the principles established in the Consortium Constitution. Should the RMT be unable to resolve any given dispute, the matter will be referred to the SC for a decision and the respective party will be expected to take any actions deemed necessary.

MANAGEMENT OF INTELLECTUAL PROPERTY

CRP intellectual property (IP) management will be aligned with the overall CGIAR Consortium Guiding Principles on the Management of Intellectual Property, which are driven by the mission of the CGIAR and the imperative that the products of the Centers' research should be international public goods.

As the CRP will work with a wide range of partners, including national agricultural research systems, advanced research institutes, civil society organizations, private sector companies, and regional and international intergovernmental organizations, the CRP will develop an IPR regime that allows all partners to honor their own IP policies without compromising the CGIAR principles. Ultimately, the Centers must produce, manage and provide access to the products of their research for use by, and for the benefit of the poor, especially farmers in developing countries.

Intellectual assets resulting from this CRP will be made available globally and publicly. Centers hold their in-trust collections of germplasm for the benefit of the world community, in accordance with agreements signed by Centers and the Governing Body of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA). All such germplasm exchanges will be conducted using the Standard Material Transfer Agreement (SMTA). All other material transfers will be done under an appropriate MTA that follows the guidelines of the Consortium's Policy on Intellectual Property.

KNOWLEDGE MANAGEMENT AND COMMUNICATIONS

In general terms, knowledge management (KM) comprises a variety of strategies and practices used to identify, create, represent, distribute, and enable adoption of insights and experiences. Such insights and experiences comprise knowledge, either embodied in individuals or embedded in organizational processes or practice. Many non-profit organizations dedicate significant resources to KM, often as a part of their fundamental business plan. The same must be done in the context of DRYLAND CEREALS.

Internally focused KM efforts typically focus on management-related objectives, such as improved organizational performance, clarity about competitive advantages and innovations, and the sharing of lessons learned. In the context of a CRP, KM efforts will overlap with monitoring, evaluating and learning (ME&L), and will both reinforce and draw on ME&L efforts. Effective KM (and of course, ME&L) will be critical to the overall success of this CRP. Given the organizational complexity of this initiative, we must be willing to invest in efforts designed to help partners obtain and share valuable insights, reduce redundant work (increasingly rely on task specialization), increase the efficiency of R4D activities and capacity strengthening efforts, retain intellectual capital as partners (and individuals) involved in the CRP change or turnover, and adapt to often rapidly changing operational environments and new opportunities.

Effective KM systems do not just happen. They require careful analysis and expert advice in their design and development. They are often most effective if developed from the ground up, i.e., if their development begins with the data, information and knowledge needed by end users – in this case smallholder farmers in dryland areas. The KM system is then designed with those ultimate needs in mind. This will help DRYLAND CEREALS partners reduce the expenditure of scarce resources on accumulating "nice to have" data and information, and keep us more focused on gathering, storing and sharing information that will facilitate the achievement of our strategic objectives and the delivery of critical outputs and outcomes that will lead to impact.

Over the past few decades, rapid developments in genomic and other molecular research technologies, as well as brisk advancements in information technologies, have combined to produce and enable the effective management of a tremendous amount of information related to molecular biology. Bioinformatics tools and geo-spatial mapping (referenced most notably under Strategic Objective 1) will be critical components of DRYLAND CEREALS' knowledge management efforts, but even these high-end information technologies will be oriented towards resolving practical problems arising from the management and analysis of very large amounts of agro-biological data and information.

Agricultural research and development communication is also undergoing a transformation, one driven by the spread of high-speed Internet connectivity; the advent of digital media; the development of new tools, platforms and methodologies; and changes in the ways the world accesses and uses information. The opportunity is before us to implement systems for the rapid, highly targeted and efficient transfer of research results, and transform them into practice and policy recommendations – while simultaneously capturing them in peer-reviewed journals and publications.

Effective and unified communication by DRYLAND CEREALS partners will require careful study and deliberate implementation of agreed guidelines. We will be operating in a complex arrangement of interlocking groups and interests, at international, regional, national and local levels. Communicating effectively in this context will be challenging, as will communicating effectively and efficiently to a wide array of stakeholders and other interested parties not directly involved in the CRP. A guiding principle for this work is that communications activities will be aligned with and promote our strategic objectives; such activities do not comprise an end in themselves. Another guiding principle is that all partners should be communicating on behalf of the CRP, and in doing so view their own organizational and individual interests as secondary to those of the overall program.

The CRP Director will have general responsibility for communicating on behalf of DRYLAND CEREALS partners to a wide variety of audiences, and will help establish and monitor – in concert with the Steering Committee and Regional/Research Program Coordinators – the program's communication action plan. Implementation of that plan will occur at all levels and be carried out by many of those involved in the R4D work, but regardless of their organizational affiliation, their communication efforts will rest on the strategic needs, interests and achievements of the CRP.

Communications work will be made an integral part of the R4D process, and not be just a by-product of it. DRYLAND CEREALS will invest in developing the communication skills of key individuals and partners – especially their ability to interact effectively with the media – and communications work will be periodically audited to ensure that resources are being spent wisely and for optimum impact.

As noted earlier, advocacy on behalf of increased investments in DRYLAND CEREALS R4D (and in markets and other needed rural infrastructure in dryland areas) is seen as a vital activity for this CRP. Such advocacy must be based on the best information available, and capitalize on the most effective communications technologies and pathways. This advocacy role will be fully integrated in the KM and Communication plan that will be developed in the early days of implementing DRYLAND CEREALS.

TIMEFRAME

CRP3.6 DRYLAND CEREALS began the proposal development process with delineating the partners' vision of realistic impacts to be achieved through collaborative R4D by 2020. We have outlined milestones (through 2014 as we will most likely start CRP activities in January 2012). Each year, the partners will conduct an extensive analysis of progress achieved relative to projected milestones and in the context of our initial priorities. Based on the results of those annual analyses, we may modify our priorities, planned activities and anticipated milestones as we go, creating a rolling three-year action plan.

DRYLAND CEREALS will continue the extensive discussions that have already been held among the initial partners and, at the same time, bring other key partners on board to help map out specific work plans for first three years of the initiative. In developing this proposal, the current partners identified general areas where they believe collaboration can be more effective. During the first six months, our focus will shift to elaborating and clarifying relative roles and responsibilities of those involved in order to effectively implement collaborative efforts and more fully realize the potential efficiencies we see, and hopefully identify others. Thus, in the first six months, a detailed business plan will be developed – one that reflects our plans for mainstreaming important gender dimensions of DRYLAND CEREALS R4D, capacity strengthening, and details regarding different research activities, technologies to be developed and/or promoted, and the relative roles of different partners and their contributions to achieving the DRYLAND CEREALS strategic objectives. As will other CRPs, during the coming six months from this submission (and regardless of approval date), we will more fully develop our gender strategy in the context of the guidelines that have been recently provided.

MITIGATING RISKS

A number of risks have been identified. First and foremost is that we will be operating in new ways with existing partners and establishing entirely new partnerships under the umbrella of DRYLAND CEREALS. There will be a relatively steep learning curve associated with the new ways of doing business that we are actively promoting in this endeavor, which may slow our progress (at least initially). A streamlined management structure and careful selection of partners involved in the CRP will help mitigate this risk, as will the simple good will that all partners will bring to the initiative.

Related to this is the need to accentuate accountability and promote ownership of DRYLAND CEREALS by the partners involved. Since many activities related to impact are beyond the control of the research program itself, we must also give emphasis to the inclusion of development agencies and extension services in research planning and implementation. Doing so may increase transaction costs, but will help mitigate the risk of limited impact on the ground.

As alluded to in other CRPs, the main risks to all are global in character, i.e. local problems are less likely to affect the overall success of DRYLAND CEREALS than are such things as continued global financial challenges, and the resulting political pressure to cut aid financing. We plan to reduce this risk by broadening our sources of finance, cultivating both public and private, and Consortium and non-Consortium sources.

Seriously inept or inefficient management combined with poor oversight presents a risk to the success of this and other CRP initiatives. Strong monitoring and evaluation, both within DRYLAND CEREALS as well as independently of it, broad-based expert advice and feedback, and an emphasis on consensus decision-making and conflict resolution will help to ameliorate management-related risks.

Dryland cereal production systems are sometimes located in areas that experience high social and political volatility, and this could affect the adoption of interventions in targeted areas. In such countries, DRYLAND CEREALS will emphasize local partnerships to minimize this risk.

As noted in CRP 1.1, while dry area systems have always been characterized by risk, these risks are changing and in some cases increasing. At the same time, the capacity to manage risk has declined as a result of restricted access to resources, lack of information, land degradation and land tenure insecurity. Resource conflicts characterize dry areas, and could be severe in some cases (e.g., the availability and control of water resources in West and Central Asia). Mitigation of such risks will be difficult, and will depend on wise counsel and full participation in community level activities, with priorities being driven locally.

Continued government policy bias against the support of smallholder farmers in marginal areas, even in the face of growing evidence of the value and importance of their enterprises, is an important risk. Efforts to speak with a unified voice to policymakers and other influential people should help reduce this risk, but policy decisions are usually not made on the basis of well-reasoned arguments or even solid scientific evidence. DRYLAND CEREALS partners will need to identify local, regional and even international 'champions' who have the ear of key policymakers and who might, over time, be able to influence the course of political decisions impinging on dryland cereal production, processing and marketing.

Finally, important risks to longer-term sustainability of DRYLAND CEREALS could include insufficient interest on the part of private sector organizations needed to push commercialization of new technologies, as well as insufficient capacity on the part of national agricultural R4D institutions to sustain the initiative well into the future. By including public and private organizations in the early stages of research planning and implementation, we believe that sustainability risks will be diminished due to a stronger sense of ownership and accountability for success.

MONITORING AND EVALUATION

DRYLAND CEREALS will generate a number of diverse outputs, including improved crop varieties, crop management technologies, information exchange, capacity building tools, and genetic and genomic resources. These outputs, which are detailed in previous sections, should result in desired outcomes that ultimately lead to the intended impacts of reducing poverty and malnutrition, enhancing food security, and reducing environmental degradation (Table 11).

The DRYLAND CEREALS monitoring and evaluation work will fully conform to the principles and standards now being established by the CGIAR Consortium, and as these become available, our monitoring and evaluation (M&E) plans and activities will be adjusted accordingly. To effectively ensure that we achieve our outcomes, *ex ante* impact assessments will be conducted during the project development stage. Building from that base, M&E studies will be conducted during the implementation of the CRP. To complete the cycle, *ex post* impact assessments will be carried out after allowing sufficient time to quantify and assess research and development impacts and to aid in priority setting.

Priorities established in this document are based on assessments found in the CGIAR Strategy and Results Framework. During implementation of DRYLAND CEREALS, ongoing M&E exercises will be performed at various levels. Partners will conduct their own internal M&E of agreed research activities. At the DRYLAND CEREALS level, the Research Management Team (RMT) will have responsibility for ensuring that proposed outputs are delivered and that expected outcomes are successful. This will require formal, annual project evaluations, as well as mid-term and end-of-program reviews by independent experts including evaluation by end users (farmers) and consumers.

We also expect that the proposed Independent Scientific Advisory Pool will provide short-term annual reviews and feedback. Given the breadth and scope of DRYLAND CEREALS, additional experts will be commissioned to provide inputs into specific activities. These will be considered by the RMT and required adjustments will be made as needed in our research planning.

Some of the major indicators to be used for M&E including:

- Enhanced genetic resources and new sources of resistance to abiotic and biotic stresses and improved nutritional quality, productivity and product quality including palatability and consumer acceptance;
- Leading-edge scientific knowledge on genetics and genomics published;
- Cultivars derived from IARC germplasm released by NARES and grown on a large-scale along with recommended crop management practices;
- Efficient private sector and informal seed production and delivery systems/models established and operating in each target country, supported by reformed national and regionally harmonized regulatory frameworks;
- Capacity building and technology delivery frameworks and options enhanced to facilitate farmers' access to validated technology such as quality seed of improved crop cultivars, crop management approaches and other farm inputs; farmer and consumer acceptance of final product and
- Publication of peer reviewed research articles, curated data sets and learning materials in granulated form to support use in multiple contexts by the partners and stakeholders.

Table 11. Monitoring and Evaluation (M&E) Framework (Process and Performance Indicators)

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Enhanced genetic resources and new sources of resistance to abiotic and biotic stresses and improved nutritional quality, productivity and product quality	Quality germplasm/ seed material Quantity of output	a) No. of accessions screened and characterized. b) Crop productivity and nutritional composition c) Consumer acceptance of product quality	Field and laboratory inspection and analysis of data generated	IARC, NARES, NGOs, Private Sector	Seasonal/Annually	Implementing/ Executing/ Independent agency
Leading edge scientific knowledge on genetics and genomics published	Publications	a) Cultivar/Variety released at regional and national level, b) Performance over time and locations, c) No. of scientific articles published in international/ national journals, books, reports, monographs.	Analysis of data on performance of crop variety at different locations. Peer review. Classification of publications by type, author, collaborator. Citation index.	IARC, NARES	Annually	Implementing/ Executing agency

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Cultivars derived from IARC germplasm released by NARES and grown on a large scale along with recommended crop management practices	Cultivar (seed material)/ Crop management Technology	a) No. of improved cultivars released under different conditions, b) Effectiveness and cost of crop management practices/technologies recommended, c) Productivity and returns per ha d) BC ratio e) Area covered and % of farmers adopting technologies	Field inspection. Visits to varietal trails, field days and demonstration plots. Analysis of field data generated. Focused group discussion	IARC, NARES	Monthly/ Quarterly	Implementing/ Executing agency
Efficient private sector and informal seed production and delivery systems/ models established and operating in each target country, supported by nationally reformed and regionally harmonized regulatory frameworks	Availability of quality seed: Breeder/Foundation/ Certified seed,	a) Quantity of seed produced and distributed at right time, place, and at right price. b) Increased seed replacement ratio. c) Reduced transaction cost of seed distribution at agency and farmer levels.	Field visits and inspection. Certification/Quality accreditation. Seed market surveys, number of dealer/agencies involved in seed supply. Reduced seed cost/unit.	Private Sector, NGOs, NARES, IARC	Half-yearly	Implementing/ Executing/ Independent agency

M&E Indicators	Type of output	Measurement	Method of M&E	Implementing Agency	Frequency	M&E Agency
Capacity building and technology delivery frameworks and options enhanced to facilitate farmers' access to validated technology such as quality seed of improved crop cultivars, crop management approaches and other farm inputs	Enhanced capacity of human resources and Gender participation	a) No. of trainings organized. b) No. of partners/ collaborators/ clients trained. c) Dissemination of gained knowledge. d) Gender wise receptivity. e) Impact on farmers' fields due to capacity building.	Review of capacity building activities. Interactive workshops/ meetings/opinion survey of beneficiaries. Initial adoption surveys. Impact analysis at farm level	IARC, NARES	Annually	Implementing/ Executing/ Independent agency
Publication of peer reviewed research articles, curated data sets and learning materials in highly granulated form to support use in multiple contexts by the partners and stakeholders	Publications/ Data sets/ Learning material	a) No. of peer reviewed articles, books, reports, monographs, policy briefs. b) No. of users of curated datasets/ learning material.	Peer review. Classification of publications by type, author, collaborator. Citation index, segregation by institution.	IARC, NARES	Annually	Implementing/ Executing agency
Impact analysis of new technology released.	Knowledge on impact	a) Impact analysis using primary and secondary data b) Sustainability of technology released	Economic impact analysis at farmer/ primary level	IARC, NARES	Beginning and End of the project	Implementing/ Executing agency

BUDGET NARRATIVE AND TABLES

The DRYLAND CEREALS budget for 2011 to 2013 has been developed following guidelines from the Consortium in terms of Window 1 and 2 funding and based on existing bilateral project funding for ICRISAT, ICARDA and the GCP. Bilateral project activities and corresponding budgets were first allocated across the CRP outputs. Additional funding from Windows 1 and 2 was then allocated based on priorities and projected expenses for each output (for each crop in each region). Each output budget represents the requirements for ICRISAT, ICARDA, the GCP and the key partners to be initially funded by DRYLAND CEREALS.

Table 12. DRYLAND CEREALS Funding Budget (USD '000)

Funding Source	2011	2012	2013	2011-2013	
ICARDA					
CGIAR Window 1 & 2: Research	1,574	1,653	1,735	**4,962**	**41%**
Bilateral Funding (secured)*	1,335	526	168	**2,029**	**17%**
Funding Gap	1,652	1,619	1,947	**5,218**	**43%**
Totals	**4,561**	**3,798**	**3,850**	**12,209**	**100%**
* includes Other Center Income					
ICRISAT					
CGIAR Window 1 & 2: Research	5,562	5,840	6,132	**17,534**	**29%**
Bilateral Funding (secured)*	10,918	8,163	4,534	**23,615**	**39%**
Funding Gap	0	6,023	13,541	**19,564**	**32%**
Totals	**16,480**	**20,026**	**24,207**	**60,713**	**100%**
* includes Other Center Income					
Generation Challenge Program					
CGIAR Window 1 & 2: Research	-	-	-	**-**	
Bilateral Funding (secured)*	1,021	934	832	**2,786**	**100%**
Funding Gap	-	-	-	**-**	
Totals	**1,021**	**934**	**832**	**2,786**	**100%**
* includes Other Center Income					
All Centers					
CGIAR Window 1 & 2: Research	7,136	7,493	7,867	**22,496**	**29%**
CGIAR Window 1 & 2: CRP Management	0	985	1,034	**2,020**	**3%**
Total CGIAR Window 1 & 2	7,136	8,478	8,902	**24,516**	**32%**
Bilateral Funding (secured)*	13,274	9,623	5,534	**28,430**	**37%**
Funding Gap	1,652	7,642	15,488	**24,782**	**32%**
Totals	**22,062**	**25,743**	**29,923**	**77,728**	**100%**
* includes Other Center Income					

DRYLAND CEREALS is projecting a total budget of US$ 77.7 million for the initial three-year period of 2011-2013 (Table 12). We are requesting that US$ 24.5 million (32%) be provided from CGIAR Windows 1 and 2 (US$ 22.5 million for research and US$ 2.0 million for CRP management). The 2011 Window 1 and 2 funding is based on the guidelines received at the time of the initiation of the CRP process. Window 1 and 2 funding in 2012 and 2013 is based on a 5% increase over the previous year budget level. Additional funding will come from already secured bilateral projects (US$ 28.4 million; 37%; see Appendix 6 for a list of the major bilateral projects included in the CRP). This leaves a current funding gap of US$ 24.8 million (32%). The funding gap could be met by additional funds being allocated by the Fund Council through the Consortium to Windows 1 and 2, or by the CRP Centers seeking additional bilateral projects if such Window funding is not available. Note that the

Generation Challenge Program (GCP) is not requesting financial support through the CRP but will continue to receive funds directly from CGIAR donors until 2013, as indicated in the GCP transition strategy, to ensure a smooth transition of its on-going research activities and contractual obligations. GCP's financial support to CGIAR Centers is reported under their respective budget as secured bilateral funding and resources reported under GCP indicates funds allocated to non-CGIAR Center partners.

Table 13. Budget by Strategic Objective (USD '000)

Strategic Objective / Output	2011	2012	2013	2011-13	
SO1 Better targeting of opportunities					
1.1 Knowledge and priorities for R4D	683	789	937	**2,409**	3%
1.2 Knowledge of trade-offs	765	889	1,058	**2,712**	3%
1.3 Evidence for policy and regulations	1,177	1,390	1,663	**4,230**	5%
Total Strategic Objective 1	**2,626**	**3,068**	**3,657**	**9,351**	**12%**
SO2 Genetic resources and tools					
2.1 Dynamic germplasm exchange and utilization	0	0	0	**0**	0%
2.2 Characterized genetic resources	1,102	1,268	1,495	**3,864**	5%
2.3 Integrated genomic and information platforms	1,152	1,314	1,536	**4,001**	5%
Total Strategic Objective 2	**2,254**	**2,582**	**3,030**	**7,865**	**10%**
SO3 Variety and hybrid development					
3.1 High grain and fodder yield	2,752	2,920	3,246	**8,919**	11%
3.2 Abiotic stresses	2,292	2,337	2,606	**7,235**	9%
3.3 Biotic stresses	1,242	1,301	1,489	**4,032**	5%
3.4 Green forage, stover and straw	644	701	826	**2,171**	3%
3.5 Enhanced nutritional grain	744	801	926	**2,471**	5%
Total Strategic Objective 3	**7,674**	**8,060**	**9,093**	**24,828**	**32%**
SO4 Sustainable crop management					
4.1 Gender responsive crop management options	1,216	1,422	1,696	**4,334**	6%
4.2 Integrated biotic stress management options	1,299	1,522	1,817	**4,638**	6%
Total Strategic Objective 4	**2,515**	**2,945**	**3,512**	**8,972**	**12%**
SO5 Effective seed and information					
5.1 Integrated technology packages	1,101	1,256	1,467	**3,824**	5%
5.2 Innovations to strengthen seed and input delivery	1,207	1,414	1,688	**4,309**	6%
5.3 Alternative communication and awareness strategies	1,124	1,314	1,567	**4,005**	5%
Total Strategic Objective 5	**3,432**	**3,985**	**4,721**	**12,138**	**16%**
SO6 Post-harvest value and markets					
6.1 Improved storage and processing technologies	1,178	1,390	1,663	**4,231**	5%
6.2 Novel and diverse products for entrepreneurs	526	596	701	**1,823**	2%
6.3 Institutional innovations to improve market linkages	518	589	695	**1,802**	2%
Total Strategic Objective 6	**2,222**	**2,575**	**3,059**	**7,856**	**10%**
Total Strategic Objectives	**20,723**	**23,214**	**27,073**	**71,010**	**91%**
Gender Research & Analysis	1,338	1,544	1,816	**4,698**	**6%**
CRP Management	0	985	1,034	**2,020**	**3%**
Total Budget	**22,062**	**25,743**	**29,923**	**77,728**	**100%**

The DRYLAND CEREALS research budget represents 97% of the total expenses and is based on projected research costs for each Strategic Objective Output (Table 13). The costs for each output represent the collective costs for ICARDA, ICRISAT and the GCP. Note that funding for the genebank core activities described under Strategic Objective 2, Output 2.1 are provide from funds approved in the Genebank Funding proposal for ICARDA and ICRISAT. A separate budget for gender research and analysis is indicated and more details provided below. For completeness, we have included the CRP management budget in the table.

Each Strategic Objective and Output is based on projected research costs for each crop in each region. Table 14 presents the 2011 expense budget by region and crop. Largest budget expenditures are targeted for pearl millet and sorghum across WCA, ESA and S Asia, and barley in CWANA

Table 14. Total 2011-2013 DRYLAND CEREALS Budget by Region and Crop (USD '000)

Strategic Objective	WCA		ESA			
	Pearl Millet	Sorghum	Barley	Finger Millet	Pearl Millet	Sorghum
SO1 Better targeting of opportunities	1,214	1,518	231	607	1,214	1,214
SO2 Genetic diversity and genomics	1,214	1,463	102	607	607	769
SO3 Variety and hybrid development	2,428	3,333	1,340	2,277	2,428	3,185
SO4 Sustainable crop management	1,214	1,214	154	1,214	1,214	1,214
SO5 Effective seed and information	1,518	1,684	154	759	1,821	1,929
SO6 Post-harvest value and markets	911	911	154	304	1,214	1,214
Total Strategic Objectives	**8,500**	**10,123**	**2,134**	**5,768**	**8,500**	**9,525**
	12.1%	**15.0%**	**3.4%**	**7.8%**	**12.1%**	**13.9%**

Strategic Objective	CWANA	S Asia			E Asia
	Barley	Barley	Pearl Millet	Sorghum	Barley
SO1 Better targeting of opportunities	390	230	1,214	1,518	-
SO2 Genetic diversity and genomics	520	153	1,214	1,214	-
SO3 Variety and hybrid development	4,270	1,150	1,821	2,125	470
SO4 Sustainable crop management	520	102	1,214	911	-
SO5 Effective seed and information	780	153	1,821	1,518	-
SO6 Post-harvest value and markets	567	153	1,214	1,214	-
Total Strategic Objectives	**7,047**	**1,973**	**8,500**	**8,500**	**470**
	11.0%	**3.1%**	**12.5%**	**12.1%**	**0.8%**

Partners are critical for the success of DRYLAND CEREALS and a total of US$ 12.8 million (17%) of the three-year budget has been allocated for them. The budget for the Generation Challenge Program (GCP) is entirely designated for partners (non-CGIAR Centers). The Center Partners budget represents funds that are provided by the CGIAR Centers directly to partners (Table 15). Several partners, especially IRD, CIRAD, INTSORMIL, ICAR and AREEO, will also make significant in-kind contributions to the CRP. These institutes and/or programs have their own source of funding to support infrastructure, salaries and operational expenses. Through better coordination of efforts under the CRP, these opportunities will be tapped to greatly enhance progress towards the goals of DRYLAND CEREALS. We will also work with each partner to help identify additional funding resources to support the work of partners in the CRP.

Table 15. Budget by Partner (USD '000)

Partner	2011	2012	2013	2011-13	
ICRISAT	14,008	17,022	20,576	**51,606**	**66%**
ICARDA	4,214	3,509	3,558	**11,281**	**15%**
GCP Partners	1,021	934	832	**2,786**	**4%**
Center Partners	2,819	3,293	3,924	**10,035**	**13%**
CRP Management	0	985	1,034	**2,020**	**3%**
Total Budget	**22,062**	**25,743**	**29,923**	**77,728**	**100%**

Personnel costs (scientific and technical salaries and supporting costs) represent the largest percentage of the budget (37%) (Table 16). Institutional management has been kept below 20%, while management of the CRP is only 2% of total costs.

Table 16. Budget by Category (USD '000)

Category	2011	2012	2013	2011-13	
Research					
Personnel Costs	8,099	9,341	11,079	**28,519**	**37%**
Supplies and Services	3,301	3,505	4,022	**10,829**	**14%**
Travel	1,302	1,462	1,717	**4,481**	**6%**
Workshops/Conferences/Training	723	728	817	**2,269**	**3%**
Capital Expenditures	582	674	800	**2,057**	**3%**
Partners	3,840	4,227	4,755	**12,822**	**16%**
Institutional Management	4,214	4,820	5,698	**14,732**	**19%**
CRP Management	0	985	1,034	**2,020**	**3%**
Total Budget	**22,062**	**25,743**	**29,923**	**77,728**	**100%**

Costs for gender research and analysis are budgeted separately and include scientists' time and operating expenses across the partners (Table 17). Approximately 6% (US$ 4.7 million) of the total first three-year budget has been specifically allocated for gender-related research. ICRISAT and ICARDA have gender specialists who will devote approximately 35% of their time to DRYLAND CEREALS conducting research on gender aspects of targeting, planning, design and implementation.

Table 17. DRYLAND CEREALS Gender Research and Analysis Budget (USD '000)

Center	2011	2012	2013	2011-13
ICARDA	217	196	201	**615**
ICRISAT	1,071	1,302	1,573	**3,946**
GCP	50	46	41	**137**
Total Budget	**1,338**	**1,544**	**1,816**	**4,698**

Given the need to effectively manage the CRP across all partners, including a number of non-CGIAR partners, a specific budget for CRP management is proposed (Table 18). Expenses are expected to start only in 2012 given the late 2011 approval expected for the CRP. The budget includes costs for the CRP Director (1.0 FTE in 2012 and 2013), 6 Strategic Objective Coordinators (0.25 FTE each in 2012 and 2013), global coordination meetings involving partners to be held at least twice each year, Research Management Team meetings twice each year, the Steering Committee to meet once physically each year and once virtually, and the travel and honoraria costs for R4D Advisory Panel members. The total management budget is 3% of the total CRP budget for 2011-2013.

Table 18. DRYLAND CEREALS Management Budget (USD '000)

Category	2011	2012	2013	2011-2013	
CRP Leadership (Director. Coordinators)	0	665	698	**1,363**	**67%**
Global Coordination Meeting	0	200	210	**410**	**20%**
Research Management Team	0	49	51	**100**	**5%**
Steering Committee	0	55	58	**113**	**6%**
R4D Advisory Panel	0	16	17	**33**	**2%**
Total CRP Management Budget	**0**	**985**	**1,034**	**2,020**	**100%**

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APPENDIX 1: OVERVIEW OF THE DRYLAND CEREALS TARGET CROPS

DRYLAND CEREALS will focus on four of the most important dryland cereals – barley, finger millet, pearl millet and sorghum – vital crops for the food security and livelihoods (including as sources of livestock feed) for millions of smallholder farmers in the drylands. What follows here are brief descriptions about these important crops.

Barley (*Hordeum vulgare* L.) is grown on 18 million hectares in developing countries, often at the fringes of deserts and steppes or at high elevations with modest or no inputs. Barley is an important food source for 60% of the population in the highlands of Ethiopia. It is also the staple food for impoverished farmers in the Andes at altitudes of 2,200-4,000 meters above sea level, due to its tolerance to cold temperatures, drought, poor soils and soil salinity. Barley grain is rich in zinc (up to 50 ppm), iron (up to 60 ppm) and soluble fibers, and has a higher content of Vitamins A and E than other major cereals.

Barley has many uses. Its grain is used as feed for animals, for malting, and as food for direct human consumption. About 75% of world barley is used for animal feed and 20% for malting, with the remaining 5% for direct food use. Barley straw is used as animal feed in many developing countries, and for animal bedding and as cover material for hut roofs. After combine harvesting, barley stubbles are grazed in summer in large areas of West Asia and North Africa. Barley is also used for green grazing or is cut before maturity and either directly fed to animals or used for silage.

Malt is the second largest use of barley, and malting barley is grown as a cash crop in a number of developing countries. Utilization for malting and by the brewing industry has picked up recently with an increase of consumption of beer and other malt products in many countries.

In the highlands of Tibet, Nepal, Ethiopia, Eritrea, in the Andean countries, and in North Africa, barley is used as human food either for bread making (usually mixed with bread wheat) or for traditional recipes. These regions are characterized by harsh living conditions and are home to some of the poorest farmers in the world who depend on low-productivity systems. In the Andes barley is the staple food for farmers at altitudes ranging from 2,200 to 4,000 meters above sea level (masl). Above 3,000 meters, barley, faba bean, potatoes and quinoa are the four crops that support human and animal life. In recent years the use of barley as food has gained momentum, especially in North America and Europe. In developed countries barley is claimed as a functional food and used in many bakery products and recipes. Barley bran flour accelerates gastrointestinal transit time, thereby reducing the incidence of colon cancer. In a 2007 ranking of cereal crops in the world, barley was fourth both in terms of quantity produced (136 million tons) and in area cultivated (566,000 km^2).

Hulless or "naked" barley is a form of barley with an easier to remove hull. Naked barley is an ancient food crop, but a new industry has developed around uses of selected hulless barley in order to increase the digestible energy of the grain, especially for swine and poultry. Hulless barley has been investigated for several potential new applications as whole grain, and for its value-added products. These include bran and flour for multiple food applications.

Global barley production has remained more or less constant over the past 30 years, though there are regional differences (Table 1-1 and Figures 1-1 & 1-2). During that period, global area under barley has decreased, but has remained fairly constant during the last decade. Yield has generally increased, with a few notable regional differences. The world average yield of barley is 2.7 t/ha, ranging from about 1.0 t/ha in Africa to more than 3.0 t/ha in East Asia, Europe, and the Americas. The average yield in developing countries is about 1.7 t/ha, and almost 3.0 t/ha in developed countries. Frequently, grain yields in the dry areas are lower than 1.0 t/ha as result of drought.

Table 1-1. Regional production share and compound annual growth rates in barley production, area harvested and productivity (SOURCE: FAOSTAT, 2010). *The production, area harvested and yield were downloaded from FAOSTAT, and three-year moving averages calculated to smooth the seasonal fluctuations. Compound annual growth rates were calculated using the smoothed data series. These growth rates describe the year-to-year growth as if each variable had grown at a steady rate.*

Region	Production Growth Rate (%)		Area Growth Rate (%)		Yield Growth Rate (%)		Regional Share (%)
	1980-94	1995-2008	1980-94	1995-2008	1980-94	1995-2008	2006-08
World	**0.21**	**-0.36**	**-0.78**	**-1.28**	**0.99**	**0.92**	**143,108.5** [1]
Africa	1.12	1.27	0.08	0.55	0.98	1.04	3.4
East Africa	-1.00	3.33	-0.30	0.91	-0.51	2.42	1.0
North Africa	1.53	0.58	0.00	0.58	1.44	0.55	2.2
North America	-1.20	-3.32	-2.27	-3.46	1.12	0.14	10.7
South America	5.30	5.08	1.89	1.75	3.32	3.30	1.7
Asia	4.44	-0.90	4.46	-2.71	0.00	1.84	14.3
Central Asia	NA [2]	-2.33	NA [2]	-5.66	NA [2]	3.56	1.8
East Asia	0.74	-2.41	0.51	-5.93	0.23	3.75	2.6
South Asia	1.40	-0.11	-1.60	-1.22	3.08	1.10	3.0
West Asia	3.43	-0.27	3.52	-1.38	-0.09	1.11	6.9
Europe	-0.54	-0.03	-2.39	-1.26	1.90	1.22	64.5
Oceania	0.92	1.28	0.08	2.80	0.84	-1.48	4.6

[1] Global average production in 1000 t for the years 2006-2008.
[2] Data available only from 1992.

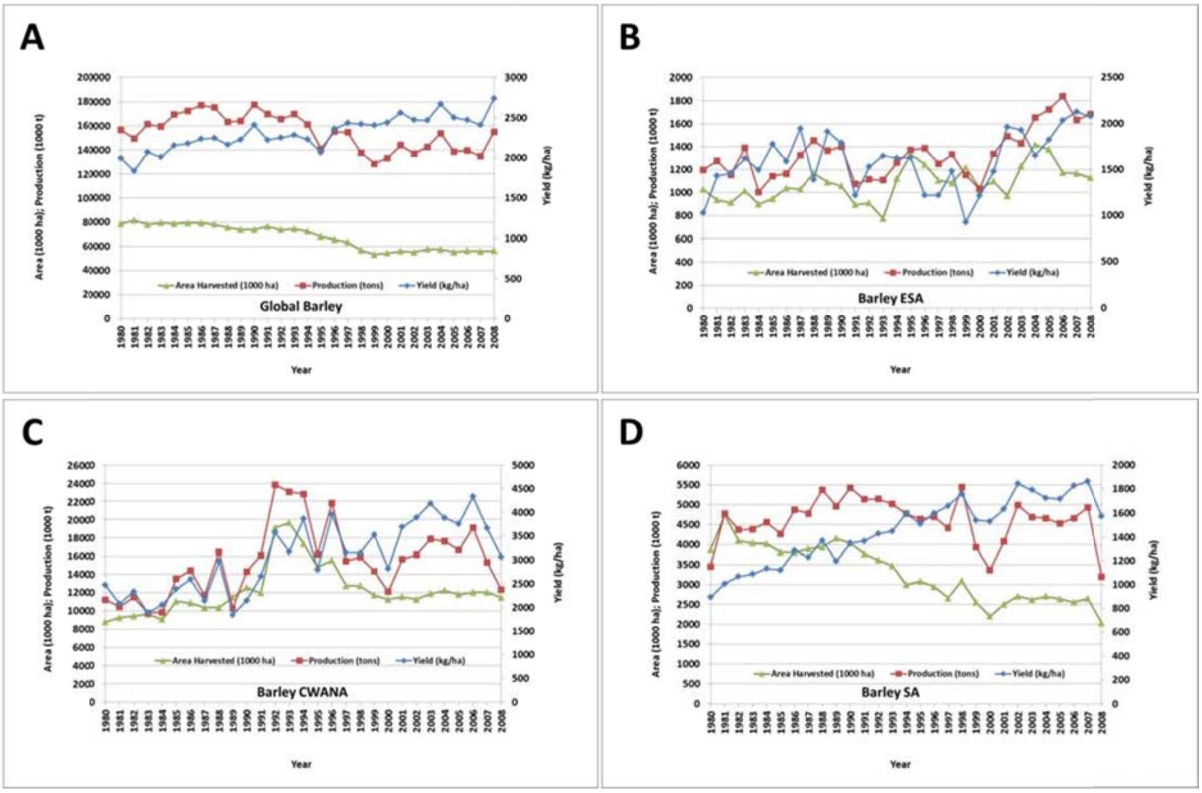

Figure 1-1. Annual barley area harvested, production and productivity statistics for the World (A), Eastern and Southern Africa (B), Central and West Asia and North Africa (C), and South Asia (D) (SOURCE: FAOSTAT, 2010)

Major constraints to barley production include stresses associated with the crop being able to withstand the most severe conditions such as drought, frost, salinity, low soil fertility, low soil pH and poor soil drainage; foliar and root diseases, such as net and spot blotch, scald, powdery mildew, fusarium head blight, rusts and dryland root rots; insects, such as Russian wheat aphids and barley stem gall midge; nematodes, such as cereal cyst nematode; and viruses, such as barley yellow dwarf virus. In some developing country barley-growing areas, the risk of crop failure is very high and the use of fertilizers, herbicides and pesticides is virtually absent.

Opportunities to be explored include: the development of improved varieties of barley for feed, food and malt uses; the possibility of barley becoming more profitable for smallholder farmers in dry areas coping with climate change, mainly rising temperatures and increasing pressure on water availability; the exploitation of rich genetic resources and available genomic tools for the identification and deployment of favorable alleles at genes contributing significantly to abiotic and biotic stress resistances, as well as to the nutritional value of grain and straw; and increased uses in alternative food products.

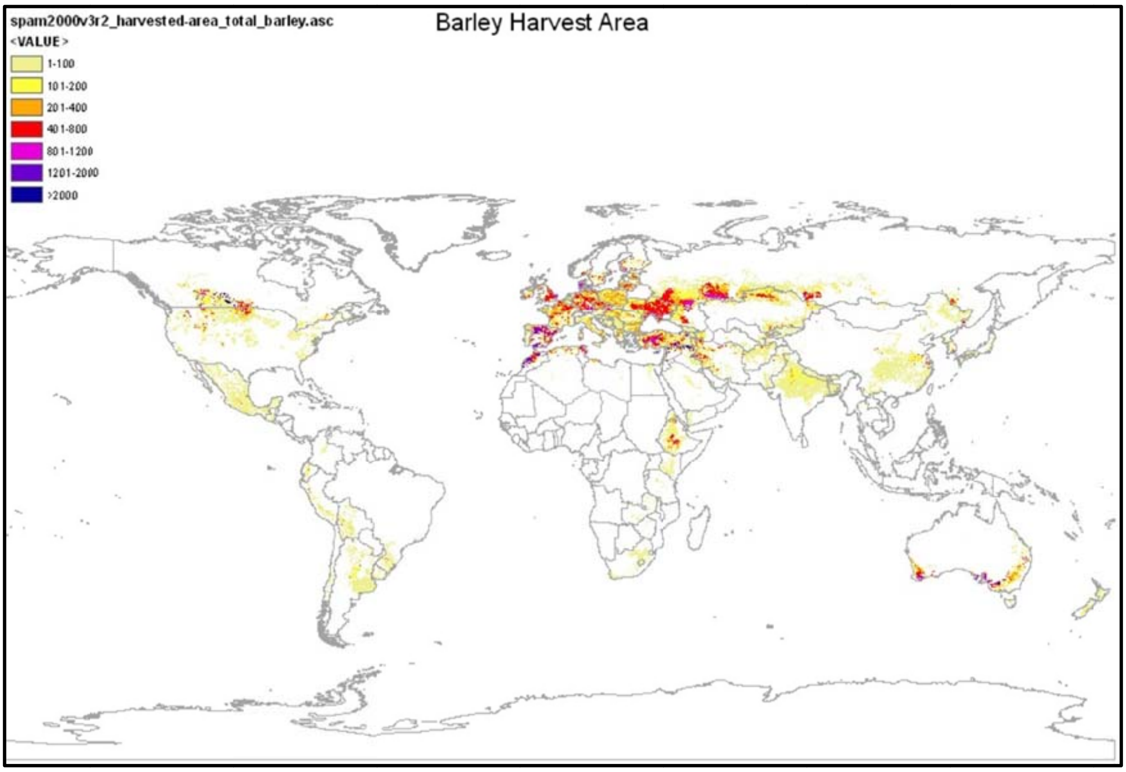

Figure 1-2. Where barley is grown (Source: ICRISAT)

Finger Millet [*Eleusine coracana* (L.) Gaertn] plays an important role in both the dietary needs and incomes of many rural households in Eastern and Southern Africa and South Asia, accounting for 10% of 38-50 million hectares sown to all the types of millet globally. Finger millet is rich in fiber, iron and calcium (containing 40 times more calcium than maize and rice, and 10 times more than wheat). It is the most important small millet in the tropics (where 12% of the global millet area is found) and is cultivated in more than 25 countries in Africa (eastern and southern) and Asia (from the Near East to the Far East), predominantly as a staple food grain. The major producers are Uganda, India, Nepal and China.

Finger millet has high yield potential (more than 10 t/ha under optimum irrigated conditions) and its grain stores very well. Still, like most so-called small millets, finger millet is grown mainly in marginal environments as a rainfed crop with low soil fertility and limited moisture. Finger millet is originally native to the Ethiopian highlands and was introduced into India approximately 4000 years ago. It is highly adapted to higher elevations and is grown in the Himalayan foothills, and East Africa highlands up to 2300 masl.

Major constraints to finger millet production include blast disease, the parasitic weed *Striga*, and abiotic stresses such as drought and low soil fertility.

Opportunities to be explored include the application of genetic male-sterility as a breeding tool (to make it easier to produce full-sib, F_1 and BC_nF_1 crosses) to facilitate recurrent selection to develop broad-based and more durable, host-plant resistance to blast, and to produce backcross F_1 generations that are large enough to permit exploitation of background selection to hasten recovery of elite recurrent parent background in breeding programs targeting value addition to farmer- and market-preferred finger millet varieties.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is the world's hardiest warm season cereal crop. It can survive even on the poorest soils of the driest regions, on highly saline soils and in the hottest climates. It is annually grown on more than 29 million hectares across the arid and semi-arid tropical and sub-tropical regions of Asia, Africa and Latin America. Pearl millet is the staple food of more than 90 million people who live in the drier areas of Africa and Asia, where its stover is also a valued fodder resource. This crop is principally used for feed and forage in the Americas, and as the mulch component of conservation tillage soya production systems on acid soils in the sub-humid and humid tropics of Brazil.

Globally, production has increased during the past 15 years, primarily due to increased yields (Table 1-2 and Figures 1-3 & 1-4). India is the largest single producer of pearl millet, both in terms of area (9.3 million hectares) and production (8.3 million tons). Compared to the early 1980s, the country's pearl millet area has declined by 19%, but production increased by 28% owing to a 64% increase in productivity (from about 450 kg/ha to 870 kg/ha in 2005-07). This has been largely due to adoption of high-yielding hybrids, mostly cultivated in areas receiving more than 400 mm of rainfall annually. During the past ten years, 33 hybrids developed both by public and private sector breeding programs, and 13 open-pollinated varieties (OPVs) developed by the public sector, have been officially released in India. In more favorable pearl millet production regions of India, the private sector is now a dominant force in hybrid development and seed delivery. Besides official releases, the private sector also markets what is called 'truthfully labeled' hybrid seed, and there are now more truthfully-labeled hybrids under cultivation than the unofficially released hybrids. A survey conducted in 2006 found that, of the more than 82 hybrids (by name) marketed by private seed companies and cultivated on about 4 million hectares, at least 60 hybrids were based on ICRISAT-bred male-sterile lines, or on proprietary male-sterile lines developed from ICRISAT-bred materials (Mula et al., 2007).

The West and Central Africa (WCA) region has the largest area under millets in Africa (15.7 million hectares), of which more than 90% is pearl millet. Since 1982, the millet area in WCA has increased by over 90%, and productivity by has risen by 12% (up from 800 to 900 kg/ha). Production has increased by about 130% (up from 6.1 to 14.1million tons), most of which has come from increases in cultivated area. Research in WCA has concentrated on OPV development, although hybrids in WCA are likely to have a significant grain yield advantage over OPVs. Eighteen OPVs, developed by ICRISAT in partnership with NARS, have been released and adopted in nine countries in the region. Because some of these OPVs were released under different names in more than one country, a total of 34 improved varieties by name have been released in the region. For instance, the most popular improved OPV, SOSAT-C88, has been released in six countries, while another popular improved OPV, GB 8735, has been released in four. Lack of seed production in the region, however, is a major bottleneck in the spread of improved cultivars – and is the primary reason that breeding research in this region has to date focused more on OPVs than hybrid cultivars although fresh seed of both OPVs and hybrids should be purchased for sowing each season.

In Eastern and Southern Africa (ESA), pearl millet is cultivated on about 2 million hectares. Sixteen OPVs have been released in 10 countries in the region, and in a few of them – such as Eritrea, Namibia, Tanzania and Kenya – smallholder adoption has been very promising. Still, as in WCA, a lack of commercial seed production and distribution continues to be the major bottleneck in the spread of improved OPVs.

Table 1-2. Regional production share and compound annual growth rates in millet (all millets, except for India) production, area harvested and productivity (SOURCE: FAOSTAT, 2010). *The production, area harvested and yield were downloaded from FAOSTAT, with the exception of data for India that were downloaded from the Indian Directorate of Economics and Statistics. Three-year moving averages were calculated for all the data to smooth the seasonal fluctuations. Compound annual growth rates were calculated using the smoothed data series. These growth rates describe the year-to-year growth as if each variable had grown at a steady rate.*

Region/ Country	Production Growth Rate (%)		Area Growth Rate (%)		Yield Growth Rate (%)		Regional Share (%)
	1980-94	1995-2008	1980-94	1995-2008	1980-94	1995-2008	2006-08
World	**0.14**	**1.59**	**0.09**	**-0.23**	**0.04**	**1.80**	**33,513.8** [1]
Africa	3.61	3.17	4.50	0.67	-0.85	2.47	54.5
ESA	0.38	1.56	1.16	0.01	-0.79	1.57	5.3
WCA	4.21	3.44	5.19	1.03	-0.94	2.39	47.0
North America	3.56	3.93	2.58	4.87	0.96	-0.92	0.9
Asia	-1.53	0.06	-2.50	-1.21	0.99	1.27	42.0
Eastern Asia	-5.52	-5.44	-7.00	-5.50	1.61	0.09	5.0
Southern Asia	0.32	1.24	-1.99	-0.81	2.35	2.04	36.0
India [2]	1.50	2.82	-1.06	2.87	2.59	3.12	27.1

[1] Global average production in 1000 t for the years 2006-2008.

[2] Data for India refers to pearl millet data sourced from the Indian Directorate of Economics and Statistics for the years 1980-2008 (2008 figures are provisional estimates).

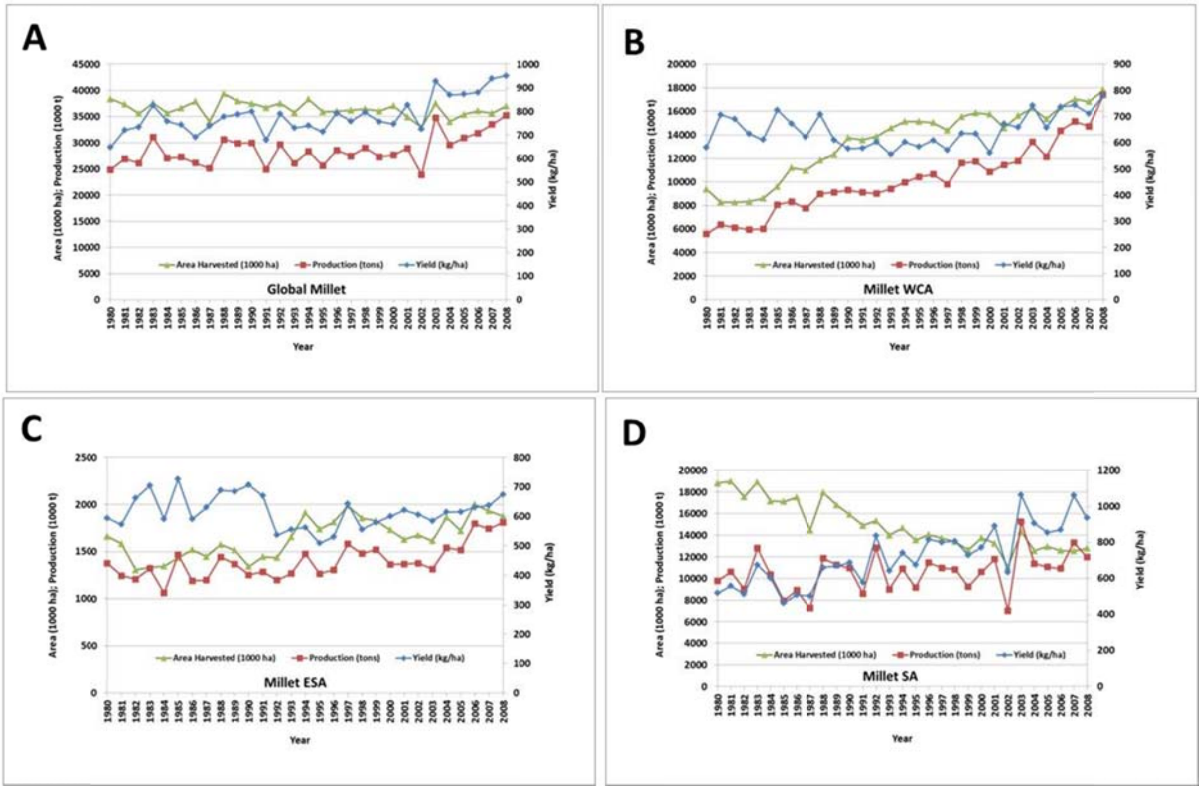

Figure 1-3. Annual millet (all millets) area harvested, production and productivity statistics for the World (A), Western and Central Africa (B), Eastern and Southern Africa (C), and South Asia (D) (SOURCE: FAOSTAT, 2010)

Besides being highly adapted to abiotic stresses, such as heat, drought, high levels of soil aluminum saturation and low levels of soil macro- and micronutrients, pearl millet has been found to be highly responsive to improved management. For instance, when cultivated as an irrigated summer season crop under intensive management conditions in parts of India, hybrids of 80-85 day duration give grain yields as high as 4-5 t/ha of grain yield. Pearl millet is a highly nutritious cereal with high protein content (11-12% with a better amino acid profile than maize, sorghum, wheat and rice) and high grain iron contents (60-65 ppm iron in improved varieties and more than 80 ppm iron in germplasm and breeding lines). High levels of dietary fiber with gluten-free proteins, and phenolic compounds with antioxidant properties further add to its health value. Research has shown the effectiveness of various processing and food products technologies to produce alternative and health foods. These can be validated for their commercialization potential, and fine-tuned where needed, or new technologies developed.

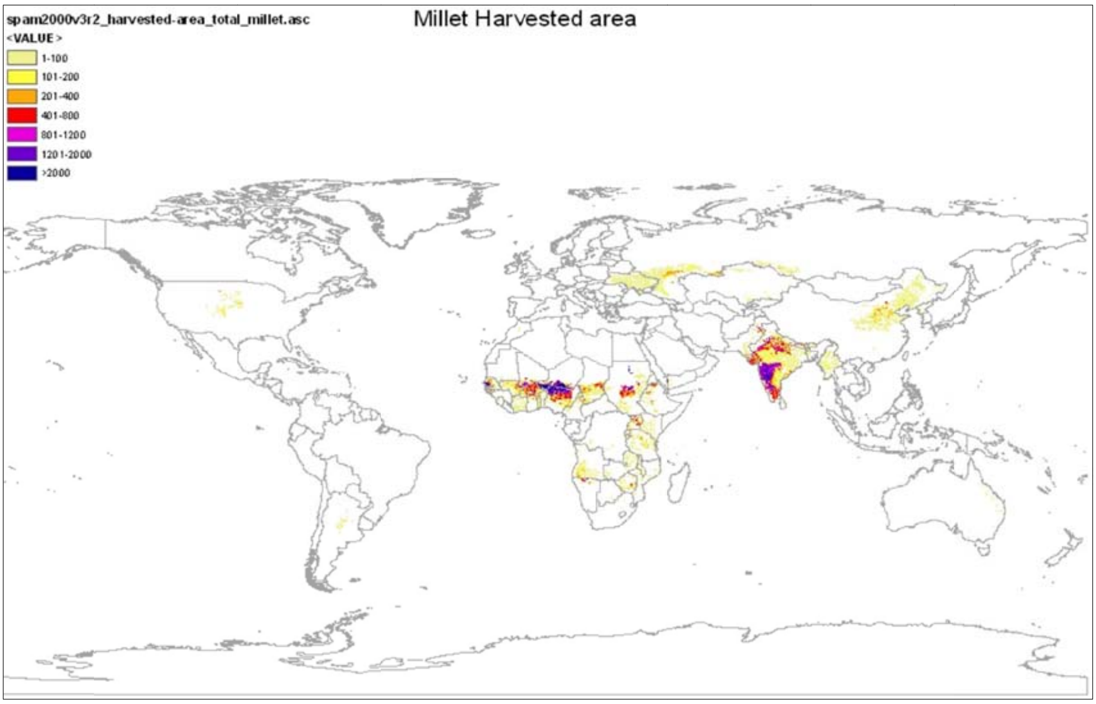

Figure 1-4. Where millets are grown (Source: ICRISAT)

Major constraints to pearl millet production include diseases such as downy mildew and blast, the parasitic weed *Striga*, and abiotic stresses such as drought, soil salinity, and high temperatures during seedling establishment and flowering time.

Opportunities to be explored include: the increased interest in hybrids in Africa building on past successes in India and on the initial heterotic grouping of pearl millet landraces accomplished in West Africa; high levels of micronutrients (iron and zinc); increased use for alternative food products, feed, and fodder; and the availability of genetic and genomic tools for identification and deployment of favorable alleles at genes contributing significantly to biotic stress resistances and abiotic stress tolerances, and nutritional value of grain, green fodder and stover (including micronutrients as well as anti-nutritional factors such as phytate and flavones). Due to its superior adaptation (compared to all other tropical cereals) to drought, soil salinity, soil acidity, and high temperatures, not to mention its food, feed and fodder values, opportunities exist for pearl millet to make inroads in new niches in Central Asia, the Middle-East, Australia and the Americas where preliminary trials have yielded encouraging results, especially with respect to its forage value.

Sorghum [*Sorghum bicolor* (L.) Moench] is cultivated in the drier areas of Africa, Asia, the Americas and Australia. It is the fifth most important cereal after rice, wheat, maize and barley, and is the dietary staple of more than 500 million people in more than 30 countries. It is grown on 42 million hectares in 98 countries of Africa, Asia, Oceania and the Americas. Nigeria, India, the USA, Mexico, Sudan, China and Argentina are the major producers. Other sorghum-producing countries include Burkina Faso, Chad, Ethiopia, Gambia, Ghana, Mali, Mauritania, Mozambique, Niger, Senegal, Somalia, Tanzania and Yemen.

Sorghum is a staple cereal in Sub-Saharan Africa, its primary center of genetic diversity. It is most extensively cultivated in zones of 600-1000 mm rainfall, although it is also important in the areas with higher rainfall (up to 1200 mm), where poor soil fertility, soil acidity and aluminum toxicity are common. Sorghum is extremely hardy and produces even under very poor soil fertility conditions (where maize fails). The crop is adapted to a wide range of temperatures, and is thus found even at high elevations in East Africa, overlapping with barley. It has good grain mold resistance and thus has a lower risk of contamination by mycotoxins. The cultivated species is diverse, with five major races identified, many of them with several subgroups. This reflects farmer selection pressure applied over millennia for adaptation to diverse production conditions, from sandy desert soils to waterlogged inland valleys, growing to maturity with only residual moisture, as well as in standing water. The grain is mostly used for food purposes, consumed in the form of flat breads and porridges (thick or thin, with or without fermentation). Sorghum grain has moderately high levels of iron (> 40 ppm) and zinc (> 30 ppm) with considerable variability in landraces (iron > 70 ppm and zinc >50 ppm) and can complement the ongoing efforts on food fortification to reduce micronutrient malnutrition globally. In addition to food and feed it is used for a wide range of industrial purposes, including starch for fermentation and bio-energy. Sorghum stover is a significant source of dry season fodder for livestock, construction material and fuel for cooking.

Sweet sorghum is emerging as a multi-purpose crop. It can provide food, feed, fodder and fuel (ethanol), without significant trade-offs among any of these uses in a production cycle. ICRISAT has pioneered the sweet sorghum ethanol production technology, and its commercialization.

Globally, sorghum production has remained more or less stable over the past 30 years, although there are notable regional differences (Table 1-3 and Figures 1-5 & 1-6). Area of production has decreased overall, but has remained essentially constant during the past five years on a global basis. West Africa, which produces roughly 25% of the world's sorghum, has seen a steady increase in total production over the past 25 years. Most of the increase up to 1995 is attributed to increases in area, although productivity increases also contributed; after 1995, yield increases explain most of the rise in sorghum production in the region. Recent global trends also show both grain yield and production increases. These gains may reflect increased use of improved varieties, better crop management practices (such as fertilizer micro-dosing), as well as increased demand due to population growth and higher world prices for major cereals. The yields of post-rainy season sorghum have steadily increased in India, and are in demand for their superior grain and stover quality.

Table 1-3. Regional production share and compound annual growth rates in sorghum production, area harvested and productivity (Source: FAOSTAT, 2010). *The production, area harvested and yield were downloaded from FAOSTAT, with the exception of data for India that were downloaded from the Indian Directorate of Economics and Statistics. Three-year moving averages were calculated for all the data to smooth the seasonal fluctuations. Compound annual growth rates were calculated using the smoothed data series. These growth rates describe the year-to-year growth as if each variable had grown at a steady rate.*

Region/ Country	Production Growth Rate (%)		Area Growth Rate (%)		Yield Growth Rate (%)		Regional Share (%)
	1980-94	1995-2008	1980-94	1995-2008	1980-94	1995-2008	2006-08
World	**-1.40**	**-0.40**	**-0.67**	**-0.08**	**-0.74**	**-0.29**	**62,218.9** [1]
Africa	2.37	2.68	3.42	1.53	-1.02	1.14	40.9
ESA	-1.62	1.65	-0.80	1.08	-0.79	0.59	7.8
WCA	4.02	3.00	5.28	1.72	-1.24	1.26	24.6
North America	-2.46	-4.74	-3.43	-4.37	1.07	-0.41	17.0
Latin America and the Caribbean	-4.81	1.76	-4.56	0.78	-0.24	1.00	19.3
Asia	-1.16	-3.39	-2.87	-2.66	1.75	-0.73	17.9
Eastern Asia	-2.73	-6.17	-5.99	-7.32	3.46	1.30	4.1
Southern Asia	-0.40	-2.44	-2.49	-2.38	2.10	-0.04	12.4
India (post-rainy season) [2]	0.52	-0.40	-1.33	-1.54	1.82	1.17	12.2
India (rainy season) [2]	0.52	-3.27	-1.33	-3.31	1.82	0.07	

[1] Global average production in 1000 t for the years 2006-2008.

[2] Data for India refers to sorghum data sourced from the Indian Directorate of Economics and Statistics for the years 1980-2008 (2008 figures are provisional estimates).

Major constraints to sorghum production include shoot fly, stem borer, head bug and aphid insect pests; grain mold and charcoal rot diseases; weed competition and the parasitic plant *Striga* (in Africa); and abiotic stresses such as drought (especially terminal drought), high temperatures, acid soils (resulting in high levels of aluminum saturation) and low soil fertility (in terms of both macronutrients like nitrogen and phosphorus, as well as micronutrients such as iron and zinc).

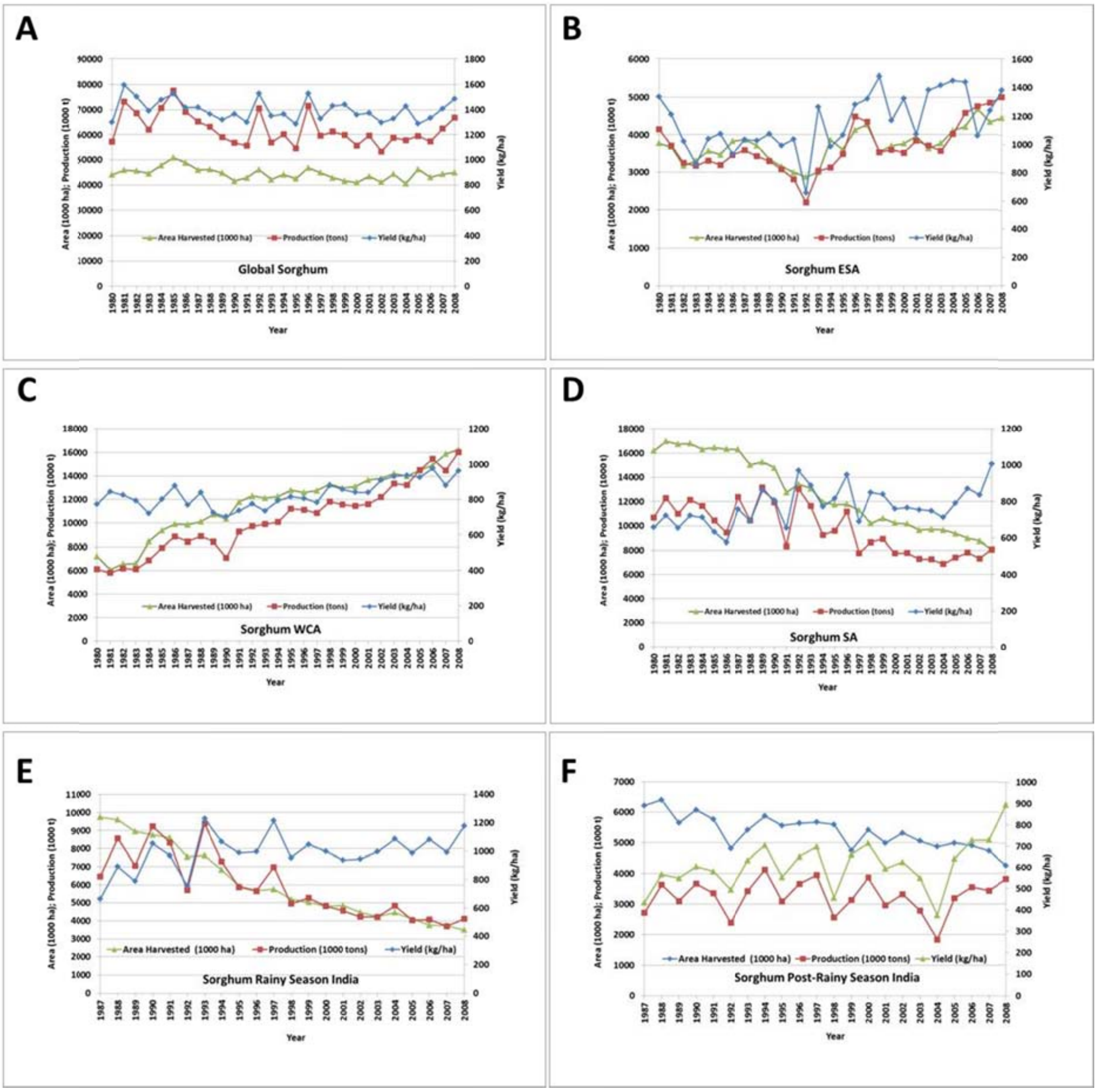

Figure 1-5. Annual sorghum area harvested, production and productivity statistics for the World (A), Eastern and Southern Africa (B), Western and Central Africa (C), South Asia (D), the rainy season in India (E), and the post-rainy season in India (F)
(Source: FAOSTAT, 2010 and the Directorate of Economics and Statistics, India, 2011)

Opportunities to be pursued include: creating hybrids to increase yields for a wider range of production systems in Africa, building on successes in India, Mali and elsewhere; and new, improved plant types for "dual purpose" sorghums for grain, feed and fodder uses that would increase the value of the crop. These new sorghum types would strengthen the integration of animal husbandry with crop production, resulting in higher and more stable incomes while improving soil health through increased organic matter cycling. The availability of the full genome sequence and other genetic and genomic tools will enable efficient use of the crop's rich genetic diversity for the improvement of sorghum and other cereals. This will facilitate the identification and transfer of favorable alleles for stress tolerance (such as phosphorus efficiency, aluminum toxicity and terminal drought), product quality (micronutrient content, digestibility and industrial qualities) and superior agronomic performance.

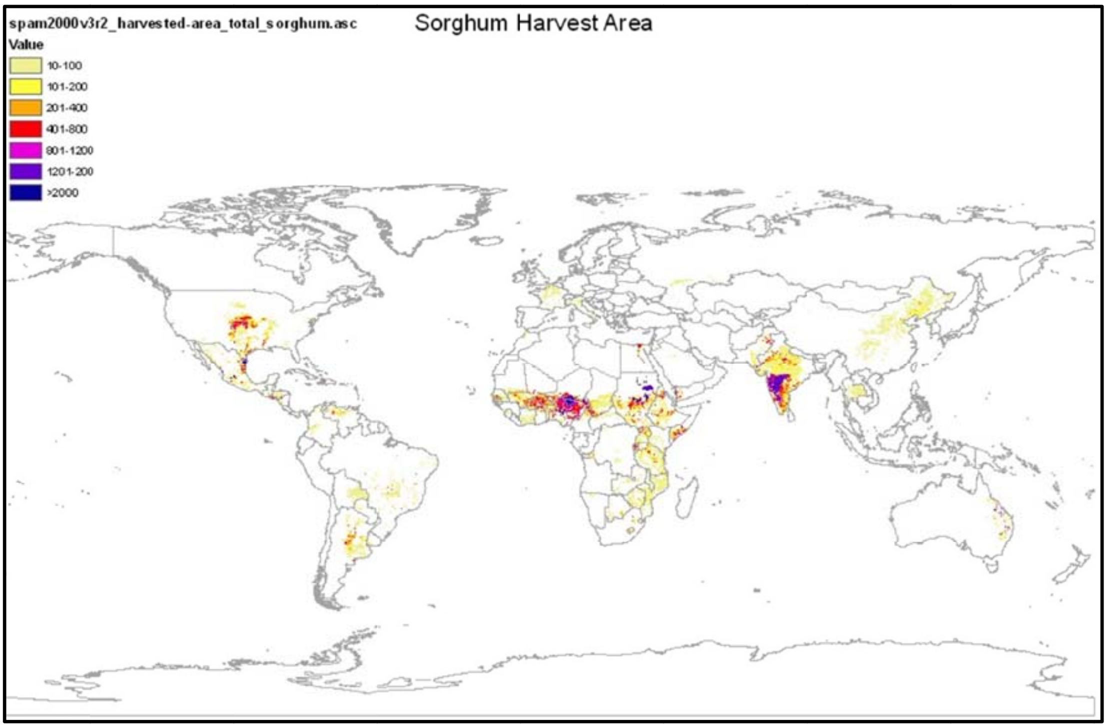

Figure 1-6. Where sorghum is grown (Source: ICRISAT)

Appendix 2: Targeted Farming Systems

Description of Priority Regions and Farming Systems for DRYLAND CEREALS

DRYLAND CEREALS will be working in four major target regions. Two of these regions are in sub-Saharan Africa: West and Central Africa (WCA) and East and Southern Africa (ESA) (Figure 2-1). A second region is Central West Asia and North Africa (CWANA), which encompasses some areas of the Middle East and North Africa (MENA - Figure 2-2), and Eastern Europe and Central Asia (CAC - Figure 2-3). The fourth region is South Asia (SA - Figure 2-4). Within these regions, we will be targeting the prevailing farming systems that feature our four focus crops (Table 2-1). These farming systems by are described below.

SUB-SAHARAN AFRICA

Maize Mixed Farming System

This farming system is the most important food production system in East and Southern Africa, extending across plateau and highland areas at altitudes of 800 to 1500 meters, from Kenya and Tanzania to Zambia, Malawi, Zimbabwe, South Africa, Swaziland and Lesotho13. It accounts for 246 million ha (10%) of the land area, 32 million ha (19%) of the cultivated area and an agricultural population of 60 million (15% of the regional total). Climate varies from dry subhumid to moist subhumid. The most typical areas have monomodal rainfall, but some areas experience bimodal rainfall.

Population density is moderately high and average farm sizes are rather modest - often less than two ha. The farming system also contains scattered irrigation schemes, but these are mostly small-scale and amount to only 6% of the irrigated area in the region. Where a bimodal rainfall pattern occurs farmers have two cropping seasons, but in drier areas they usually harvest only once a year from a given field. The main staple is maize and the main cash sources are migrant remittances, cattle, small ruminants, tobacco, coffee and cotton, plus the sale of food crops such as maize and pulses. About 36 million cattle are kept for ploughing, breeding, milk, farm manure, bride wealth, savings and emergency sale. In spite of scattered settlement patterns, community institutions and market linkages in the maize belt are relatively better developed than in other farming systems.

Socio-economic differentiation is considerable, due mainly to migration, and the whole system is currently in crisis as input use has fallen sharply due to the shortage of seed, fertilizer and agro-chemicals, plus the high price of fertilizer relative to the maize price. As a result, yields have fallen and soil fertility is declining, while smallholders are reverting to extensive production practices. The main sources of vulnerability are drought and market volatility. There is a moderate incidence of chronic poverty, linked to small farm size and absence of draught oxen and migrant remittances. Recently transitory poverty has sharply increased as a result of retrenchment of off-farm workers coupled with policy reforms affecting maize. In spite of the current crisis, long term agricultural growth prospects are relatively good and the potential for reduction of poverty is high.

Cereal-Root Crop Mixed Farming System

This farming system extends from Guinea through Northern Côte d'Ivoire to Ghana, Togo, Benin and the mid-belt states of Nigeria to Northern Cameroon; and there is a similar zone in Central and Southern Africa. It accounts for 312 million ha (13%) of the land area of the region – predominantly in the dry subhumid zone – 31 million ha (18%) of the cultivated area and supports an agricultural population of 59 million (15% of the region). Cattle are numerous – some 42 million head. Although the system shares a number of climatic characteristics with the Maize Mixed System, other characteristics set it apart, namely; lower altitude, higher temperatures, lower population density, abundant cultivated land, higher livestock numbers per household, and poorer transport and communications infrastructure. Although cereals such as maize, sorghum and millet are widespread, wherever animal traction is absent root crops such as yams and cassava are more important than cereals. Intercropping is common, and a wide range of crops is grown and marketed.

The main source of vulnerability is drought. Poverty incidence is limited, numbers of poor people are modest and the potential for poverty reduction is moderate. Agricultural growth prospects are excellent and, as described in the relevant section below, this system could become the bread basket of Africa and an important source of export earnings.

Agro-Pastoral Millet/Sorghum Farming System
This farming system occupies 198 million ha (8%) of the land of the region, generally in the semiarid zone of West Africa from Senegal to Niger, and in substantial areas of East and Southern Africa from Somalia and Ethiopia to South Africa. It has an agricultural population of 33 million (8%) and their density is modest, but pressure on the limited amount of cultivated land is very high. Crops and livestock are of similar importance. Nearly 22 million ha are used for crops – 12% of the cultivated land in the region. Rainfed sorghum and pearl millet are the main sources of food and are rarely marketed, whereas sesame and pulses are sometimes sold. Land preparation is by oxen or camel, while hoe cultivation is common along riverbanks. The system contains nearly 25 million head of cattle as well as sheep and goats. Livestock are kept for subsistence (milk and milk products), offspring, transportation (camels, donkeys), land preparation (oxen, camels), sale or exchange, savings, bride wealth and insurance against crop failure. The population generally lives permanently in villages, although part of their herds may continue to migrate seasonally in the care of herd boys.

The main source of vulnerability is drought, leading to crop failure, weak animals and the distress sale of assets. Poverty is extensive, and often severe. The potential for poverty reduction is only moderate. Agricultural growth potential is also modest and presents important challenges.

Pastoral Farming System
This system is located in the arid and semiarid zones extending from Mauritania to the northern parts of Mali, Niger, Chad, Sudan, Ethiopia, Eritrea, Kenya and Uganda. There are also pastoral areas in the arid zones of Namibia and in parts of Botswana and Southern Angola. The system occupies 346 million ha (14%) of the regional land area, but accounts for only 27 million (7%) of the agricultural population and 21 million cattle, as well as sheep, goats and camels. During the driest period of the year, Sahelian pastoralists move south to the Cereal-Root Crop Mixed System areas and they return north during the rainy season.

The main source of vulnerability is the great climatic variability and consequently high incidence of drought. Socio-economic differentiation is considerable - many herders have lost most of their animals due to droughts or stock theft. Poverty incidence is extensive, but the potential for poverty reduction is low. Agricultural growth potential is also modest.

Highland Temperate Mixed Farming System
This farming system occupies 44 million ha (only 2%) of the land area of the region and accounts for six million ha (4%) of cultivated area, but supports an agricultural population of 28 million (7% of the total in the region). Most of the system is located at altitudes between 1800 and 3000 meters in the highlands and mountains of Ethiopia. Smaller areas are found in Eritrea, Lesotho, Angola, Cameroon and Nigeria, generally in subhumid or humid agro-ecological zones. Average population density is high and average farm size is small (1-2 ha). Cattle are numerous (estimated population of 17 million) and are kept for ploughing, milk, manure, bride wealth, savings and emergency sale. Small grains such as wheat and barley are the main staples, complemented by peas, lentils, broad beans, rape, tef (in Ethiopia) and Irish potatoes. The main sources of cash are from the sale of sheep and goats, wool, local barley beer, Irish potatoes, pulses and oilseeds. Some households have access to soldiers' salaries (Ethiopia and Eritrea) or remittances (Lesotho), but these mountain areas offer few local opportunities for off-farm employment. Typically there is a single cropping season, although some parts of Ethiopia have a second, shorter season. There are major problems in the farming system: for instance, soil fertility is declining because of erosion and a shortage of biomass; and

cereal production is suffering from a lack of inputs. There is, however, considerable potential for diversification into higher-value temperate crops.

Household vulnerability stems mainly from the risky climate: early and late frosts at high altitudes can severely reduce yields, and crop failures are not uncommon in cold and wet years. As with other food-crop based farming systems, a hungry season occurs from planting time until the main grain harvest. Poverty incidence is moderate to extensive - in comparison with other systems in Africa - except for the periodic droughts that afflict the Horn of Africa. The potential for poverty reduction and for agricultural growth potential is only moderate.

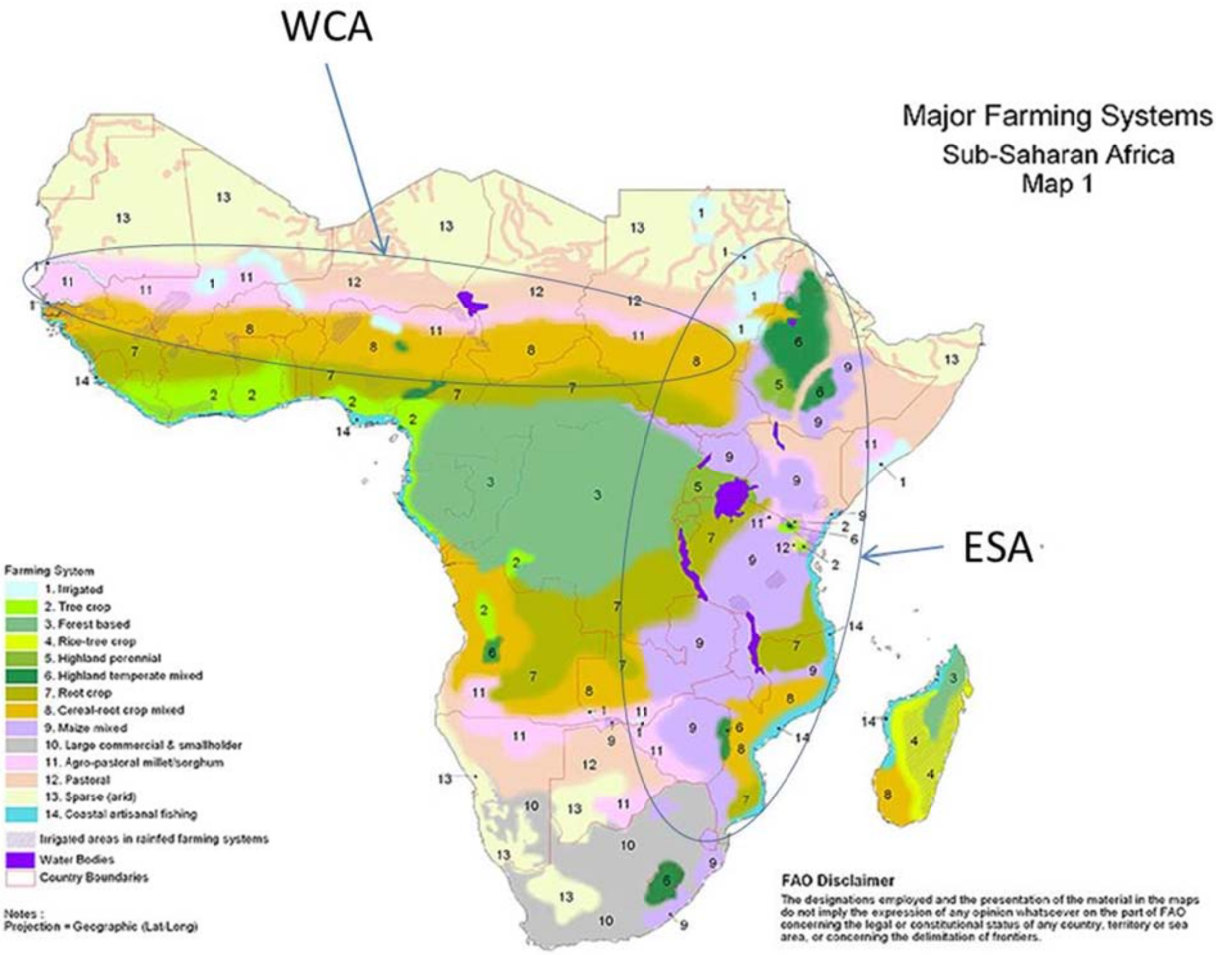

Figure 2-1. Map showing the targeted primary farming systems for DRYLAND CEREALS in Western and Central Africa (WCA) and Eastern and Southern Africa (ESA)

Map source: FAO Farming Systems - http://www.fao.org/farmingsystems/regions_en.htm

MIDDLE EAST AND NORTH AFRICA

Dryland Mixed Farming System

The Dryland Mixed Farming System is found in dry subhumid areas that receive an annual rainfall of between 150 to 300 mm. The system contains an agricultural population of 13 million people and includes 17 million ha of cultivated land. Population density tends to be lower than in the other main arable systems and average farm sizes are larger. The main rainfed cereals are barley and wheat grown in a rotation that includes an annual or two-year fallow, but the risk of drought is high and considerable food insecurity exists. The livestock, including six million cattle and a greater number of small ruminants, interact strongly with the cropping and fodder system. In good years, rainfed barley is grown for grain, but when there is insufficient rainfall for adequate maturation, it is common for it to be fed as fodder to livestock. Local barley varieties are particularly well adapted to this system. The development of higher value crops, such as fruits and vegetables, has been constrained not only by low rainfall, but also by relatively poor market linkages. Poverty is extensive among small farmers.

Highland Mixed Farming System

The Highland Mixed Farming System is the most important system in the region in terms of population – with 27 million people engaged in agriculture - but contains only 74 million ha (7%) of the land area, thus leading to moderately high population densities. The cultivated area is 22 million ha, of which nearly five million ha are irrigated. It covers two, sometimes overlapping, sub-systems. The first is dominated by rainfed cereal and legume cropping, with tree crops, fruits and olives on terraces, together with vines. In Yemen, this sub-system includes qat and coffee, which are traditionally the most important tree crops in mountain regions. The second sub-system is based primarily on the raising of livestock (mostly sheep) on communally managed lands. In some cases, both the livestock and the people who control them are transhumant, migrating seasonally between lowland steppe in the more humid winter season and upland areas in the dry season. This type of livestock keeping is still important in Iran and Morocco. Poverty within this system is extensive, as markets are often distant, infrastructure is poorly developed and the degradation of natural resources is a serious problem.

Rainfed Mixed Farming System

The Rainfed Mixed Farming System contains almost 18% of the agricultural population but occupies only 2% of the land area, resulting in high population densities. Cultivated area is 14 million ha, including tree crops and vines; and there are about eight million cattle. Although the system is by definition principally rainfed, an increasing area (presently about 0.6 million ha) is now benefiting from the availability of new drilling and pumping technologies, which have made it possible to use supplementary winter irrigation on wheat and full irrigation on summer cash crops. There is some dry-season grazing of sheep migrating from the steppe areas. The more humid areas (600 to 1000 mm annual rainfall) are characterized by tree crops (olives and fruit), melons and grapes. There is also some protected cropping with supplementary irrigation, for potatoes, vegetables and flowers. Common crops are wheat, barley, chickpeas, lentils, and the fodder crops – vetches and medics. Poverty is moderate, but would be higher without extensive off-farm income from seasonal labor migration.

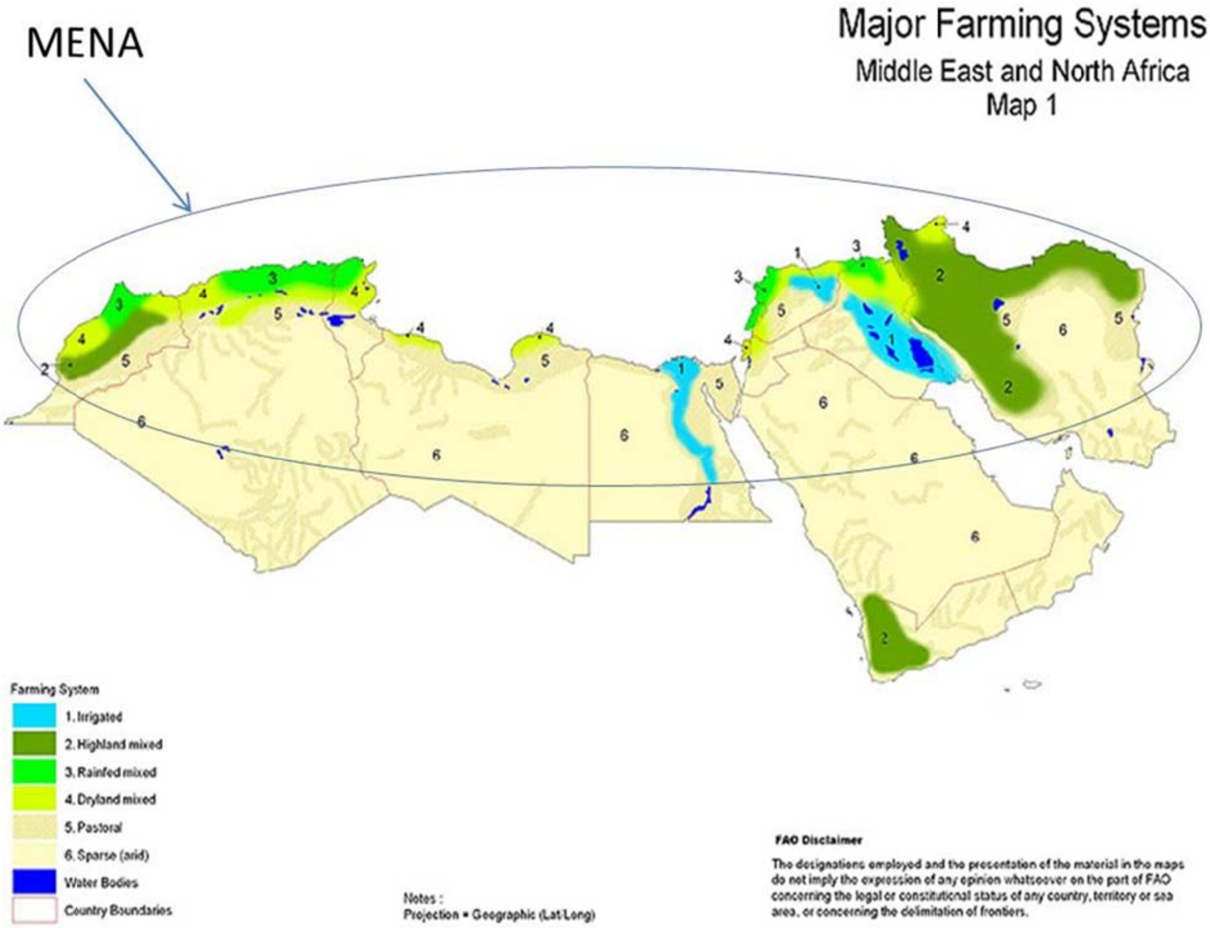

Figure 2-2. Map showing the targeted primary farming systems for DRYLAND CEREALS in the Middle East and North Africa (MENA)

Map source: FAO Farming Systems - http://www.fao.org/farmingsystems/regions_en.htm

EASTERN EUROPE AND CENTRAL ASIA

Pastoral Farming System

This is a system that is typical of much of Southeastern Central Asia. It covers an estimated 82 million ha and has a sparse agricultural population of about 9 million people. Rural populations constitute a large proportion of the total population, reaching over 60% in Kyrgyzstan. Most of the pastures are in high mountainous areas or adjacent dry zones. Principal livestock species are sheep with some cattle. Although the dominant activity is pastoralism, about 14 million ha in mountain valleys with slightly more favorable conditions are used for cultivation of cereals, fodder crops and potatoes for subsistence. Herd management is based on spring and autumn grazing of communal pastures close to the villages. Summer grazing is on distant, often heavily overgrazed, mountain pastures, while in winter stall-feeding predominates. Due to excessive animal populations, poor pasture management and overgrazing, deterioration of natural vegetation and soil erosion are important issues. Wool production, which was a major output during the Soviet era, has fallen dramatically since the early 1990s, while meat output has increased as farmers have reverted to the sturdy traditional meat breeds. Poverty is particularly widespread in this system.

Small-scale Cereal-Livestock Farming System

This system is located in the semiarid and dry subhumid and mountainous zones of Turkey with a growing period of less than 180 days. It contains an estimated agricultural population of 4 million and covers an area of 35 million ha, of which nearly 8 million ha are farmed by owner-managers or tenants. Private ownership has led to better farm management, intensification of labor use and diversification of production. However, many farms created by land distribution are very small and some are hardly viable. Tenancy arrangements foster neither short-term productivity nor long-term resource management. The main cereals are wheat and barley. Unreliable precipitation means that yields, and hence production of these rainfed crops, vary considerably from year to year. Nevertheless, small or subsistence farmers within this system produce most of Turkey's grain. Farm households consume about half of the wheat crop; the other half is marketed through commercial channels. Barley is almost exclusively used for animal feed or for export. Sheep and goats are the main livestock and play an important role in the system; but some cattle are also raised. There is some crop-livestock integration arising from traditional practices. Animals forage on crop stubble, weeds, and grass on fallow land and uncultivable grazing areas. Overgrazing of grasslands, wasteland, forests and mountain meadows is common, with substantial environmental damage and low livestock productivity.

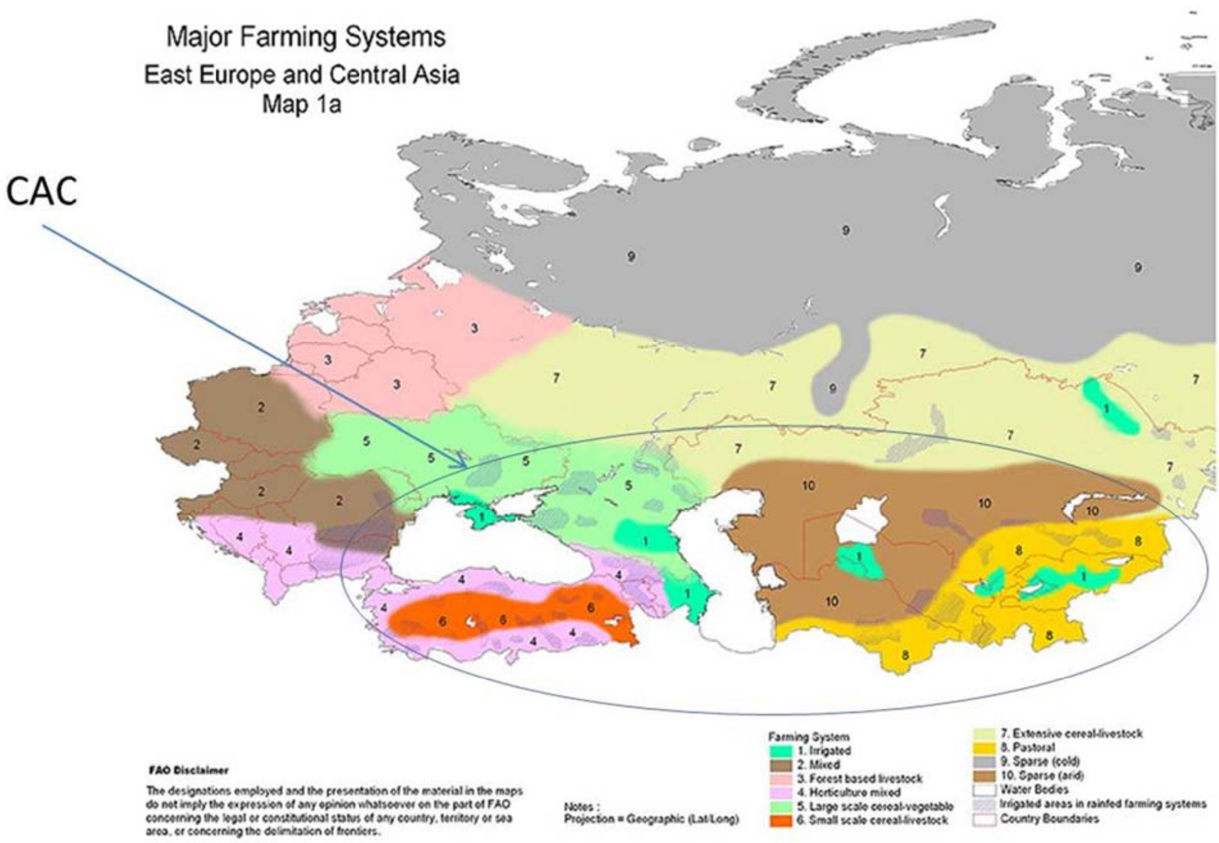

Figure 2-3. Map showing the targeted primary farming systems for DRYLAND CEREALS in East Europe and Central Asia (EECA)

Map source: FAO Farming Systems - http://www.fao.org/farmingsystems/regions_en.htm

SOUTH ASIA

Rice-Wheat Farming System

Characterized by a summer paddy crop followed by an irrigated winter wheat crop (and sometimes also a short spring vegetable crop), the Rice-Wheat Farming System forms a broad swathe across Northern Pakistan and India, from the Indus irrigation area in Sindh and Punjab, across the Indo-Gangetic plain to the northeast of Bangladesh. Total system area is 97 million ha with an estimated 62 million ha – more than 60% of the land of the system – under cultivation. An estimated 48 million ha, or 78 of the cultivated area, is irrigated. The system has a significant level of crop-livestock integration, with an estimated 119 million bovines, which produce draft power and milk, as well as manure for composting. Around 73 million small ruminants are kept, principally for meat. Of the total system population of 484 million people, 254 million are classified as agricultural. The Rice and Rice-Wheat Farming Systems together contain 40% of the cultivated land in the region and produce the bulk of the marketed food grains that feed the cities and urban areas of South Asia.

Rainfed Mixed Farming System

This predominantly rainfed cropping and livestock farming system occupies the largest area within the sub-continent and, with the exception of a small area in Northern Sri Lanka, is confined entirely to India. Total system area is 147 million ha with an estimated 87 million ha (59%) under cultivation. Rice and some wheat are grown, as well as pearl millet and sorghum, a wide variety of pulses and oilseeds, sugarcane, and vegetables and fruit. An estimated 14 million ha, or 16% of the cultivated area, is irrigated. There are an estimated 126 million bovines and 64 million small ruminants, which are partially integrated with cropping. Of the total system population of 371 million, 226 million are classified as agricultural. In many instances, relatively small areas are irrigated from reservoirs and in recent decades, tubewells have contributed to an elevated level and stability of cereal production. Vulnerability stems from the substantial climatic and economic variability. Poverty is extensive and its severity increases markedly after droughts.

Dry Rainfed Farming System

Located in a `rain shadow' surrounded by the Rainfed Mixed Farming System in the Western Deccan, this farming system has a higher proportion of irrigation than the moister surrounding areas, allowing it to support a similar range of irrigated and rainfed crops despite the drier climate. Total system area is 18 million ha with an estimated 10 million ha – about 53% – under cultivation. An estimated 3.5 million ha, or 36% of the cultivated area, is irrigated – and this irrigation is a central determinant of the farming system. Of the total system population of 45 million, nearly 30 million are classified as agricultural. Because of the prevalence of irrigation, vulnerability is somewhat lower than in the neighboring Rainfed Farming System, and thus the level of poverty is moderate.

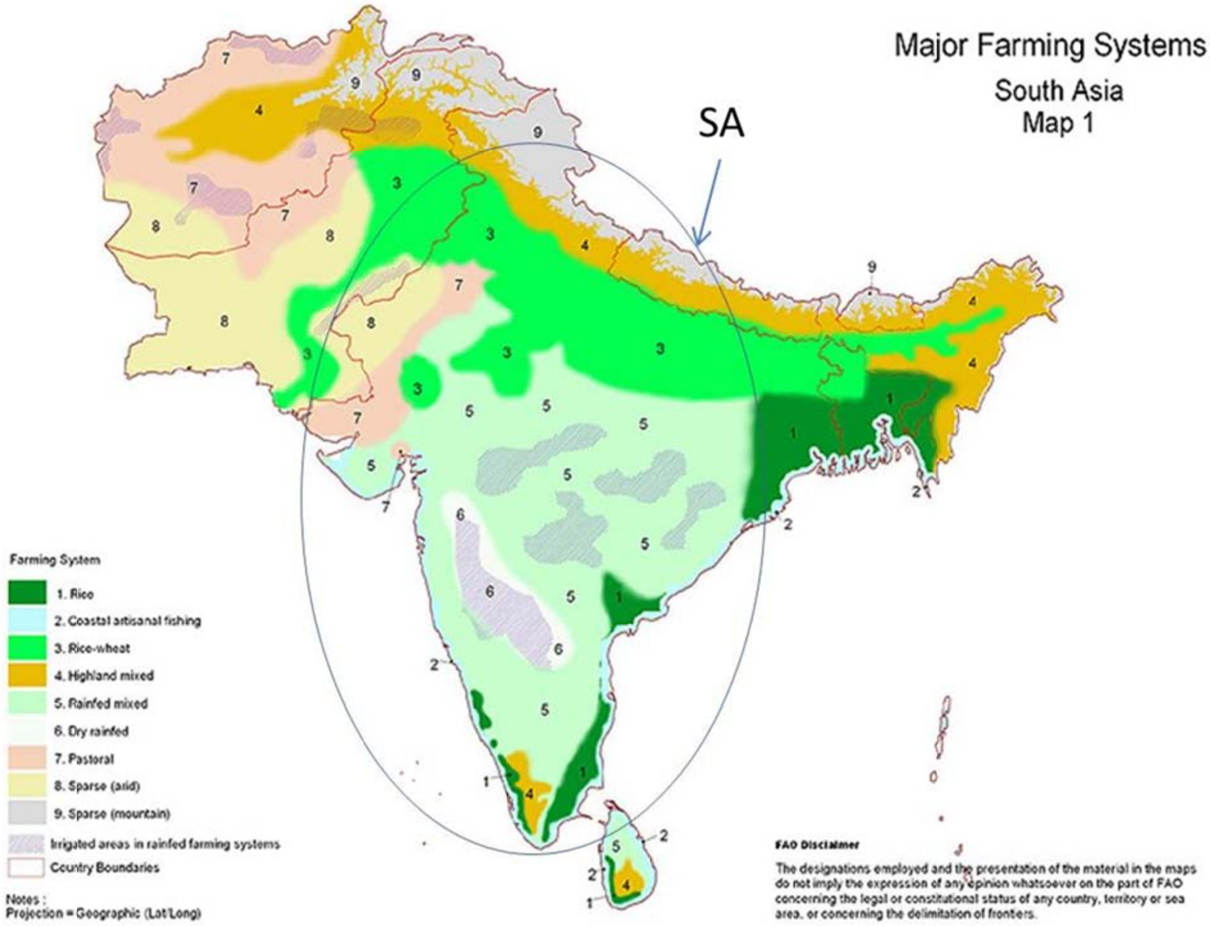

Figure 2-4: Map showing the targeted primary farming systems for DRYLAND CEREALS in South Asia (SA)

Map source: FAO Farming Systems - http://www.fao.org/farmingsystems/regions_en.htm

Table 2-1. Population, stunted children, drought probability, number of poor, and area in farming systems with more than 800,000 hectares of dryland cereals (barley, finger millet, pearl millet, and sorghum). Data for farming systems and regions were extracted from the Priority Setting Framework for the Generation Challenge Program data site (https://groups.google.com/group/farming-systems-group) and expert opinion.

Region	Farming system	Rural pop. (million)	Urban pop. (million)	Stunted children (million)	Prevalence of stunting (%)	Drought probability	Poor (<US$ 1.25/day) in farming system (million)	Barley area (ha)	Finger millet area (ha)	Pearl millet area (ha)	Sorghum area (ha)	Total area plated to dryland cereals	Proportion of area planted to dryland cereals (%)
West and Central Africa (WCA)	Cereal root crop mixed	46.05	9.73	3.96	38.91	10.88	35.57	-	-	3,841,000	5,335,000	9,176,000	39.60
	Agro-pastoral millet/sorghum	29.78	11.42	2.21	37.53	43.69	28.62	-	-	6,938,000	3,706,000	10,644,000	54.20
	Pastoral	7.13	1.74	0.87	41.43	72.22	7.28	-	-	3,452,000	1,948,000	5,400,000	67.50
	Subtotal for WCA	**82.96**	**22.89**	**7.04**	**38.79**	**42.26**	**71.47**	**0**	**0**	**14,231,000**	**10,989,000**	**25,220,000**	**51.74**
Eastern and Southern Africa (ESA)	Maize mixed	70.99	22.17	6.19	43.02	31.49	48.92	124,000	740,000	-	1,294,000	2,158,000	11.10
	Cereal root crop mixed	21.49	4.59	2.19	48.73	24.55	15.72	5,000	-	436,000	1,001,000	1,442,000	40.70
	Agro-pastoral millet/sorghum	8.08	5.41	0.92	41.33	59.74	2.25	12,000	50,000	501,000	1,035,000	1,598,000	61.00
	Pastoral	22.48	8.25	2.36	42.50	67.58	6.09	103,000	-	855,000	2,068,000	3,026,000	49.50
	Highland temperate mixed	35.96	6.78	2.68	52.01	24.22	17.81	1,185,967	242,000		473,000	1,900,967	39.90
	Subtotal for ESA	**159.00**	**47.20**	**14.34**	**45.38**	**41.51**	**90.79**	**1,429,967**	**1,032,000**	**1,792,000**	**5,871,000**	**10,124,967**	**40.07**
Central and West Asia, North Africa (CWANA)	Dryland mixed	18.09	29.13	0.75	20.54	18.94	1.13	2,299,849	-	5,631	3,855	2,309,335	36.30
	Highland mixed	31.04	36.07	1.57	38.68	32.86	3.65	1,171,254	-	58,161	167,588	1,397,003	20.31
	Rainfed mixed	13.85	24.96	0.49	16.93	6.69	1.67	1,294,046	-	3,599	18,806	1,316,451	29.96
	Pastoral	15.76	9.69	0.54	28.57	12.41	7.29	1,291,569	-	38,344	1,746	513,669	12.35
	Small scale cereal-livestock	8.76	11.14	0.38	19.60	2.59	0.66	1,693,334	-	16,424	-	1,709,758	22.23
	Subtotal for CWANA	**87.5**	**110.99**	**3.73**	**28.77**	**14.70**	**2.88**	**7,750,052**	**0**	**122,159**	**191,995**	**7,246,216**	**27.05**
South Asia (SA)	Rice-wheat	365.49	125.9	28.29	54.29	25.06	237.31	674,208	16,650	2,870,048	580,387	3,705,733	6.00
	Rainfed mixed	249.34	107.43	24.54	63.46	10.16	157.81	96,100	1,122,053	3,399,449	4,237,303	9,008,636	11.00
	Dry rainfed	33.54	12.06	3.61	65.50	32.50	18.07	0	42,515	1,090,868	2,817,739	3,951,122	30.00
	Subtotal for SA	**648.37**	**245.39**	**56.44**	**58.99**	**22.57**	**413.19**	**770,308**	**1,181,218**	**7,360,364**	**7,635,429**	**16,665,490**	**14.39**
Grand Total		**977.83**	**426.47**	**81.55**	**42.98**	**30.26**	**578.33**	**9,950,327**	**2,213,218**	**23,505,523**	**24,687,424**	**59,256,673**	**36.22**

APPENDIX 3: DEMAND PROJECTIONS AND VALUE PROPOSITION

DEMAND FOR DRYLAND CEREALS

Demand for dryland cereals was estimated using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model, developed by IFPRI. The model projects supply and demand for major commodities from baseline in 2000 over a 50-year period. The model allows separate projections for sorghum and millet but not for barley, which is aggregated in 'other commodities that includes oats and rye. Demand for cereals is disaggregated into food and feed demand. The main demand drivers in the model are population growth and GDP, both of which are based on 'medium' World Bank projections.

Table 3-1 shows demand projections for the target countries, using the baseline IMPACT model. The results show positive trends in demand for dryland cereals in all regions. In the baseline model, between 2000 and 2020, demand in our target countries is expected to grow from 23 to 35 million mt for sorghum, and from 21 to 29 million mt for millet. Since the IMPACT model does not disaggregate barley from other cereals, it was not possible to estimate predicted demand for barley. However, barley is expected to share in the rising demand for other cereals. In our target countries, barley is produced on 18 million ha leading to a production of 22 million mt.

Table 3-1.Demand projections for dryland cereals, 2020 (000 mt) from baseline IMPACT model

Region	Sorghum[1]		Millet		Barley[2]	
	2000	2020	2000	2020	2000	2020
WCA	9,435	15,580	9,772	16,009	-	-
ESA	6,633	10,732	2,028	3,431	4,378	7,180
CWANA	-	-	-	-	38,072	53,942
SA (India)	7,706	8,798*	9,680	10,360	66,421	95,502
Total	**23,774**	**35,110**	**21,480**	**29,800**	**108,873**	**156,624**

[1]All figures are for grain and exclude sorghum grown for forage in India

[2]Calculated based on percentage of barley within demand figures of other cereals (barley, rye, oats)

The IMPACT model can be used to **indicate** the likely long-term trend in demand. Because the IMPACT model takes account of own and cross price elasticities of different commodities, yield growth rates, rainfall and other factors, such as yield reductions due to water deficit, price of inputs like labor and fertilizer) in projecting supply, its projections are not directly comparable with the increases in supply projected in the CRP. The CRP estimates of increase in production (on which the estimation of benefits is based) suggest that the CRP estimate for sorghum is ***slightly below*** predicted demand. However, the CRP estimate for increase in the supply of millet is **above** the predicted demand. This is mainly due to the CRP production estimate for India, and the introduction of improved hybrids of pearl millet. In ESA, the increase in supply estimated by the CRP is below demand and in WCA the increase is slightly above. No comparison is possible for barley since it is grouped with other cereals.

Table 3-2.Projected increase in supply by 2020, with DRYLAND CEREALS technology change

Region	Sorghum	Millet	Barley
WCA	17,551	18,622	_
ESA	7,222	2,528	1,976
CWANA	_	_	25,840
SA (India)	9,270	14,755	1,891
Total	34,044	35,905	32,208

Per capita demand for all cereals falls as incomes rise and consumers diversify diets into meat and milk products. Within the cereals, per capita consumption of dryland cereals falls relatively faster because rising incomes allow consumers to switch to preferred cereals like maize and rice. Nevertheless, **aggregate demand** for dryland cereals will continue to rise because of population growth, and lack of alternatives in to these crops in dryland areas. Additional demand will also be created by new markets for sorghum (brewing, substituting for expensive barley) and millet (health-conscious consumers). On balance, therefore, we can expect continued growth in demand where (1) population growth remains high (2) there are no alternative cereal crop and (3) where growth in income is not expected to rapidly increase consumer demand for preferred cereals. In Asia, rising incomes have reduced per capita consumption of dryland cereals, but not sufficiently to reduce aggregate demand. Demand projections for dryland cereals in India show that to 2020 demand will continue to exceed (Kumar, Rosegrant, and Hazell, 1995). Demand for sorghum products remains high in specific regions of India (Parthasarathy Rao et al., 2011). Demand for sorghum in India is driven by demand for feed, in response to rising consumer demand for meat and dairy products, as well as for food. Of the total demand for sorghum of 8,798,000 t projected for India by the baseline model, 90% is for food. However, this figure does not include the production of sorghum for forage in the rice-wheat farming system. Demand for dryland cereals in Sub-Saharan Africa has not previously been studied and is the focus of current research, with ongoing surveys in both WCA and ESA of the demand by processors and studies of consumer demand based on national household expenditure surveys.

The supply shift estimated by the CRP is supported by evidence of increasing in global demand for dryland cereals by 2020. The likely scale of increase in demand was estimated using IFPRI's IMPACT model, which gives estimates for sorghum and millet, but not for barley. Results from the baseline model (based on historical trends) show positive demand trends for sorghum and millet in all our target regions. By 2020, demand for sorghum and millet in our target countries is expected to reach 35 million and 30 million mt, respectively. This is below the increase in supply that we estimated for sorghum (34 million mt), but above the increase in supply estimated for millet (36 million mt), largely because of expected technology breakthroughs with pearl millet hybrids in India. Based on available evidence, therefore, the CRP will assist farmers meet rising demand for dryland cereals. From the 22 million mt of barley production in developing countries, barley demand for malt is increasing in countries such as Iran, India, Ethiopia and Latin America. Demand for barley for human consumption is increasing in countries such as Morocco, Ethiopia and Iran. Overall demand for barley for animal feed is increasing in almost all countries and supply does not meet the demands in developing countries. There is also a huge barley production in the developed world and in countries such as Russia, Turkey that can fill gaps to some extent. The demand for Barley was calculated based on percentage of barley within demand figures of other cereals (barley, rye, and oats).

VALUE PROPOSITION FOR DRYLAND CEREALS

Production estimates of barley, millets and sorghum
Production estimates (in metric tons) for the base year (2011) were taken from FAOSTAT, average of three years 2007-2009. Production estimates for 2020 were estimated in two stages:

First, we estimated the expected yield increase from (1) genetic improvement and (2) crop management. These yield increases were based on personal knowledge by plant breeders and agronomists, and published literature (Sanders et al., 1996; Twomlow et al., 2008; Mazvimavi et al., 2008; Mazvimavi and Twomlow, 2009). Second, we estimated the increase in production by projecting an increase in adoption for (1) improved varieties and (2) improved crop management practices for each year between 2012 and 2020. The expected increase in adoption was made by scientists in each region, based on personal knowledge of each country. The estimates were made separately for each country in the region.

FAOSTAT does not distinguish between finger and pearl millet. Both are grown in East and Southern Africa. The proportion planted to each type of millet in ESA was based on published literature (FAO/ICRISAT, 1996: Appendix III) and personal knowledge of ESA plant breeders.

Value of production
Values in 2011 are producer prices in current US$ available for sorghum and millet. Figures derive from FAOSTAT and are not available for all countries in each region. Where prices were not available for a target country, we used the mean value for the region, based on producer prices for target countries for which prices were available. Values for 2020 are undiscounted 2011 prices.

Food Security
Food security was measured as the number of households in each country that can meet at least 30 % of basic kilocalories from a specific dryland cereal crop. This was estimated in three stages. First, we estimated the population for each country in areas where sorghum and millet were grown, using the HarvestPlus database. Second, we estimated the average household size from the FAOSTAT database, which is based primarily on decennial farm census data. Since figures were not available for each target country, we used a regional average household size, based on the mean of target countries for which data on household size was available. Third, mean household size was converted to adult equivalents (AE) assuming that each household had only two adults, with adults weighted as 1 and children as 0.5. Finally, we estimated the annual calorific requirement per adult based on a requirement of 2100 kcals/day, and kcal values per 100 grams of 339 (sorghum), 378 (millet) and 352 (barley) from the USDA nutrient database.

Table 3-3. Food Security from dryland cereals

Region	Persons/household	AE/household	Kcal/household/30%
WCA	9	5.5	1,264,725
ESA	5	3.5	804,825
SA	5	3.5	804,825
WANA	5	3.5	804,825
EA	3	2.5	574,875

Added Net Income
Additional income from dryland cereals was measured as the additional net income per ha from adoption of improved varieties of dryland cereals, measured in current US$, in 2020. Net income is therefore the difference in income per ha from unimproved and improved varieties, after subtracting cash costs and excluding the cost of family labor and non-purchased inputs (e.g. land, manure, etc.). Income refers to the producer price of grain, and excludes stover. The main sources

of data were recent unpublished baseline surveys for the HOPE Project (sorghum and millet) (Table 3-4). Since this data was not available for all target countries, we used a regional average based on target countries for which data was available. Added income by crop and by country was then calculated by taking the area planted to improved varieties of dryland cereals in 2020, and multiplying by added income per hectare in Table 3-4.

Table 3-4. Added net income from adoption of improved varieties (US$/ha)

Region/crop	Added net income
WCA sorghum	50
WCA millet	50
ESA sorghum	50
ESA millet	50
SA sorghum	90
SA millet	150
Barley	50

Additional Farmers Reached

This was measured as the number of farm households that had adopted improved varieties of dryland cereals by 2020. This was estimated in four stages.

First, we estimated the average holding size for each region, using the same FAO database that was used to estimate household size (see section 3, Food Security). Since figures were not available for all target countries, we used a regional average based on the mean holding size for target countries for which figures were available. Second, we assumed that 75% of the average holding was planted to the staple dryland cereal. Third, we assumed that farmers adopting improved varieties would plant 50 % of this area to improved varieties, with the remaining 50% planted to unimproved varieties (Table 3-5). Fourth, we divided the area planted to improved varieties in 2020 in each country by the average area planted to improved varieties per holding in Table 3-5.

Table 3-5. Estimation of added farmers reached

Region/crop	Average holding size (ha)	Area planted to dryland cereals (75%)	Area planted to improved varieties (50%)
WCA sorghum	4	3	1.50
WCA millet	4	3	1.50
ESA sorghum	1.5	1.125	0.56
ESA millet	1.5	1.125	0.56
SA sorghum	1.3	0.975	0.49
SA millet	1.3	0.975	0.49
Barley	2	1.5	0.75

This was measured in mt required to plant the area planted to improved varieties of sorghum, barley, and millets in 2020. The estimation was made in two steps. First, we measured the seed rate for each crop. The figures we used were 8 kg/ha (sorghum), 4 kg/ha (millets) and 100 kg/ha (barley). Second, we divided the total area under improved varieties by the seed rate per ha, and converted the result to mt of seed required. The seed requirement variable serves as a check on the validity of the estimates of adoption.

Value of stover
The value of stover was measured only for sorghum, based on the assumption that straw of millets and barley was used as fuel or feed. Values are producer prices for sorghum stover measured in current USD. The change in the value of stover was estimated based on the following assumptions. First, we estimated the grain: stover ratio for unimproved varieties and for improved varieties for sorghum. Second, we estimated the grain: stover price ratio in 2011 and 2020. We assumed that this ratio would stay constant for SA. For WCA and ESA, we assumed that the ratio would increase with rising demand for stover. Third, (for SA) only) we estimated the price premium (10%) that market traders would pay for improved sorghum varieties with higher quality stover that improved *in vitro* digestibility.

Table 3-6. Estimation of benefits from stover

Region	Grain: Stover ratio (mt)		Grain: Stover price ratio (%)		Quality premium (%)
	2011	2020	2011	2020	2020
WCA	10	4	10	20	0
ESA	5	3	10	20	0
SA	2	2	50	50	10

These ratios were based on personal knowledge of plant breeders in each region, as well as published literature (Blummel and Rao, 2006; Kristjanson and Zerbini, 1999; Gebremedhin et al., 2009; EADD, 2011). Information for WCA was obtained from de Leeuw (1997) and Clerget et al., 2010). Information for value of stover for WCA is spare but Falconnier (2009) documents how farmers have started to store and use sorghum stover. Values for newer varieties of sorghum were published recent as an abstract (Clerget et al., 2010).

For the value we have no information that research has not been done, as the stover is only rarely traded so far. We have started to observe that farmers harvest and store sorghum stover of improved quality, and that it is major reason for adoption of new varieties (Gatien-Falconnier, 2009).

These ratios were then applied as follows. To measure the value of stover in 2011, we multiplied the total sorghum production by the grain: stover ratio, to obtain a figure for total stover production in 2011. We then multiplied this figure by the grain: stover price ratio for 2011, to obtain a total value.

To measure the value of stover in 2020, the calculations were made separately for improved and unimproved varieties. For unimproved varieties, we multiplied the total production of unimproved varieties in 2020 by the grain: stover ratio in 2011 (i.e. the original ratio) to obtain total stover production from unimproved varieties. We then multiplied this figure by the grain: stover price ratio for 2020 to obtain the value of stover from unimproved varieties in 2020. For improved varieties, we multiplied the total production of improved varieties in 2020 by the grain: stover ratio for 2020 (i.e. the new ratio), to obtain total stover production from improved varieties in 2020. We then added the value of stover from improved and unimproved varieties in 2020 to obtain the total value of stover in 2020.

Finally (for SA only) we added the price premium (10 to the value of stover from improved varieties in 2020. This was estimated as the premium that market traders would pay for improved sorghum varieties with higher quality stover that improved *in vitro* digestibility.

The value of stover for SA includes the value of forage sorghum, for which production was estimated to increase from 60 to 75 million t between 2011 and 2020. This was valued at the price for stover used to value stover produced from sorghum grown for grain. No price premium was added.

Nutrition

Benefits from nutrition were measured as the percentage of nutrient requirements for the population met from production of dryland cereals. This was estimated in two stages. First, we measured the supply of micronutrients from dryland cereals. This was made by multiplying the production of cereals by the nutrient values for calcium, iron, and zinc, using the values in Table 3-7.

Table 3-7. Nutrient values for dryland cereals (mg per 100 grams)

Mineral	Barley	Sorghum	Millet
Iron	2.5	4.4	3.01
Zinc	2.13	0	1.68
Calcium	29	28	8

Source: USDA, except for sorghum where values for iron and zinc are for decorticated grain

Second, we estimated the demand for micronutrients in the target population. For each target country, the target population was measured as the total population in the area where the dryland cereal was grown. This assumes that the cereal is consumed entirely within the area in which it is being grown. Next, we estimated the nutrient requirement for this target population (Table 3-8).

Table 3-8. Nutrient requirements for iron, zinc, and calcium (mg or g/day)

Nutrient	mcg/d	mg/d	g/d	Measure
Iron	8100	8.1	0.0081	EAR
Zinc	6800	6.8	0.0068	EAR
Calcium		1000	1	AI

Note: EARs represent the estimated nutrient requirement so that 50% of the population will meet their nutrient requirements. This is in contrast to RDAs or RNIs (which most people are familiar with), which represents the estimated nutrient requirement so that 97% of the population will meet their requirements. I selected the highest adult EAR available, excluding pregnant and lactating women. The EARs are per the Canadian/US guidelines for iron and zinc. Calcium is unique (http://www.nap.edu/catalog.php?record_id=5776); an EAR could not be set by an expert committee so they set Adequate Intakes (AIs) of 1000 mg/day per adult.

Table 3-9. Value propositions to 2020 for Dryland Cereal Crops and Regions

Region/Crop	Production (mt)		Seed required (mt)	Value (USD)		Food security (hh)		Increase in net income (USD)	Increase in farmers reached	Stover (USD)	
	2011	2020	2020	2011	2020	2011	2020	2020	2020	2011	2020
WCA											
Sorghum	14,661,356	17,551,467	28,816	4,474,217,697	5,374,155,957	39,298,662	47,045,387	180,101,928	2,401,359	4,474,217,697	9,668,386,002
Millet	15,157,273	18,622,460	3,849	4,275,951,384	5,312,146,005	8,305,355	10,204,088	228,560,266	3,047,470		
ESA											
Barley	1,815,524	1,976,500	52,800	821,391,987	894,472,035	7,940,415	8,644,463	26,399,973	938,666		
Sorghum	6,622,710	7,222,808	33,360	1,983,794,408	2,187,833,369	27,895,489	30,423,160	207,404,000	7,374,364	991,897,204	3,025,649,521
Millet	1,713,000	2,528,466	4,647	1,345,278,291	1,771,100,127	11,912,726	15,817,556	55,699,500	1,980,427		
China											
Barley	2,318,000	2,491,129	18,791	484,462,000	520,645,961	14,193,277	15,253,358	9,395,700	385,465		
India											
Barley	1,690,000	1,891,231	31,200	382,785,000	428,363,822	7,391,420	8,271,529	15,600,000	640,000		
Sorghum	7,515,420	9,270,600	24,899	2,033,000,993	2,335,833,484	31,655,669	39,048,655	281,016,000	6,404,923	4,020,000,000	5,036,754,145
Millet	12,842,710	14,755,739	5,658	2,033,000,993	2,335,833,484	60,318,012	69,302,884	212,163,000	2,901,374		
WANA											
Barley	19,810,598	21,858,220	494,316	5,645,670,921	6,230,983,931	86,644,059	95,599,583	204,632,980	5,456,879		
CAC											
Barley	3,741,350	3,982,781	35,469	717,014,738	5,281,996,965	16,363,249	17,419,177	17,734,555	472,921		

TOTALS

Region/Crop	Production (mt)		Seed required (mt)	Value (USD)		Food security (hh)		Increase in net income (USD)	Increase in farmers reached	Stover (USD)	
	2011	2020	2020	2011	2020	2011	2020	2020	2020	2011	2020
WCA	29,818,629	36,173,927	32,665	8,750,169,081	10,686,301,962	47,604,017	57,249,475	408,662,194	5,448,829	4,474,221,546	9,668,386,002
ESA	10,151,234	11,727,774	90,807	4,150,464,686	4,853,405,531	47,748,630	54,885,179	289,503,473	10,293,457	991,954,651	3,025,649,521
India	22,048,130	25,917,570	61,757	3,680,631,179	4,324,439,286	99,365,101	116,623,068	508,779,000	9,946,297	4,905,391,630	6,045,294,936
China	2,318,000	2,491,129	18,791	484,462,000	520,645,961	14,193,277	15,253,358	9,395,700	385,465	18,791	-
WANA	19,810,598	21,858,220	494,316	5,645,670,921	6,230,983,931	86,644,059	95,599,583	204,632,980	5,456,879	494,316	-
CAC	3,741,350	3,982,781	35,469	717,014,738	5,281,996,965	16,363,249	17,419,177	17,734,555	472,921	35,469	-
Barley (- China)	27,057,472	29,708,732	613,785	7,566,862,646	12,835,816,753	118,339,143	129,934,752	264,367,508	7,508,466	613,785	-
Millet	29,712,983	35,906,665	14,154	7,654,230,668	9,419,079,616	80,536,093	95,324,528	496,422,766	7,929,271	14,154	-
Sorghum	28,799,486	34,044,875	87,075	7,722,857,291	9,122,231,306	98,849,820	116,517,202	668,521,928	16,180,646	10,371,506,531	18,782,966,949
GRAND TOTALS	**85,569,941**	**99,660,272**	**715,014**	**22,943,950,605**	**31,330,469,695**	**297,618,442**	**341,376,706**	**1,429,312,202**	**31,618,383**	**10,371,506,531**	**18,782,966,949**

Appendix 4: Strategic Objective Outputs, Methodology, Milestones & Partner Roles

Strategic Objective 1 - Better targeting of opportunities for technology development and delivery of dryland cereals to smallholder farmers in Africa and Asia

Outputs, methodologies and milestones

Output 1.1 Knowledge and priorities for R4D opportunities along the dryland cereals value chain to increase benefits to smallholder farmers, especially women

Dryland cereals primarily grown by smallholder farmers primarily for direct human consumption are also being used to produce various value added products that are becoming additional source of income especially for women. Over the decades the composition and demand for dryland cereals has undergone a swift change from a subsistence crop (staple) towards commercial production for the market as raw material for livestock, and poultry feed, potable alcohol, starch and ethanol industries, besides value added food products enhancing the incomes of small holders. However, underdeveloped markets, markets that mainly cater to grain for food purposes, small marketed quantities, market access and weak value chains act as major limiting factors preventing small scale farmers from reaping benefits from growing demand in various uses. Uncoordinated and unreliable supplies with associated high costs to end users could lead to diversion of demand to other substitute crops that have better linkages with the demand centers. These limiting factors can be very different and diverse depending on the type of product, market demand, market type and infrastructure.

Experience illustrates that investment in market institutions, value chains, processing and innovations to reduce marketing costs and better provision of market information acts as drivers of change owing to the economic and competitive needs to reduce transaction cost, stimulate market demand and trade. It is therefore important to understand costs associated along the supply chain until the end user. This would provide a basis for the incentives for production, processing, and other improvements at each stage of the distribution chain. The detailed cost and return structures of individual value chain commodities will help to identify the areas of investment, improvement, innovations and opportunities for R4D to have greatest impact on profitability of small holder farmers and women.

Traditionally, outreach and extension services have focused on improving productivity and production and ignored post-harvesting processing, marketing and value addition. The linkages among producers, value chain actors and consumers were often unexplored. Thus, the “value chain” from input suppliers through production to output markets needs to be explored. This must involve multiple actors such as input suppliers, producers, storage agencies, food technologists, processors, and marketing entities.

Policy-makers need to be made aware of the opportunities that dryland cereals present for addressing both rural poverty and supplying food to rapidly growing urban populations. Dryland cereals primarily grown by smallholder farmers for consumption are also being used to produce value added products especially for livestock (e.g. sorghum and maize). However, the potential of dryland millets in addressing the diabetic and obese populations is still unexploited. Under-developed markets, poor outreach, niche markets, markets that mainly cater to grain for local and ethnic food purposes, small marketed quantities, low market access and weak value chains have deterred smallholder farmers from reaping benefits from growing these low input, low water, high value but low demand crops (Chandrakanth and Akarsha, 2011).

Uncoordinated and unreliable supplies with associated high costs to end users can lead to crop substitution losing the rich wealth of dryland agro-biodiversity that can ably support farmers in the wake of climate change. Recent studies conducted by ICRISAT have identified that nearly 30-40% of sorghum and 50-60% pearl millet production in India is being utilized for alternative uses (as livestock feed) (Basavaraj et al., 2011 and Parthasarathy et al., 2010).

The preliminary results generated from this output will be used in identification of major non-food sub-sectors in the market for dry land cereals. Each identified major sub-sector for each selected crop will be analyzed. A representative sampling procedure will be designed by incorporating a sizeable proportion of all stakeholders involved in sub-sector. Primary data will be collected through pre-tested schedules from stakeholders. The data will be analyzed with appropriate statistical tools and techniques. The costs and returns from different sub-sectors will be calculated based on the primary data and would be compared among different sub-sectors. Similarly, the producer farmer costs and returns per ha will be calculated. Ultimately, the producer share in the total profitability would be generated among alternative uses and sectors. The actual value-addition among different sub-sectors will be analyzed along with the reasons and steps for assured value addition will be explored. The preferred traits and qualities of each sub-sector, which will help in generating new cultivars/hybrids by research organizations/ institutes will be explored. Markets, institutions, value chains, processing and innovations to reduce marketing costs and better provision of market information reduce transaction costs, stimulating effective demand. Thus, the costs associated with supply chain are crucial. This provides basis for the incentives for production, processing, and other improvements in the distribution chain. The detailed cost and return structures of individual value chain commodities will help to identify the areas of investment, improvement, innovations and opportunities for R4D to have greatest impact on the economy of small holder farmers and farm women.

Methodology

Participatory value chain analysis (mapping market channels, transaction costs)

The first step is to document the R4D in value addition of all the dry land cereals. With multiple stakeholders and products produced along the value chain for dryland cereals, understanding the market systems, their behavior in the systems in terms of opportunities and obstacles, interactions and inter-linkages of the stakeholders involved and mapping of the value chains are critical. Hence, a participatory type of value chain approach will be meaningful with involvement of diverse actors of the chain and specifically the value chains in dryland cereals can be explored with the effective participation of the farmwomen. The mapping will provide critical insights into the disaggregation of costs and returns, opportunities for value addition, challenges faced across various stakeholders along the value chain, distributional distortions and leverage points for policy and technical interventions. The indicative value chain costs and returns for dryland cereals, market prices of grain and stover, input use statistics, market margins together with the maintenance of monitoring data sets for specific projects, case studies will assist setting priorities among crops, regions, markets and approaches. Analysis of comparative economics and costing of the products produced will be attempted for their competitiveness. In addition, private and social cost benefit analysis will be done in order to assess the gains accrued among different players in the chain. The value chain framework thus, will help to focus and improve decision-making around priorities and investments and to identify development activities along the value chain of dryland cereals.

The first step is to document the R4D in value addition of all the dry land cereals. The value chains in dryland cereals can be explored with the effective participation of the farm women using these crops in their meal preparations and linking them with food technologists and entrepreneurs who can undertake processing and this needs to be linked with the commercial brand equity owners such as Britannia, Parle, Kissan and other companies, who can herald the use of millets in their products. The participatory value chain will only be meaningful with involvement of diverse actors of the chain.

Milestones

- Mainstreamed gender plans for dryland cereals (2012)
- Identify end market opportunities for dryland cereals (2013)
- Completed Value Chain Analysis for 2 crops in 2 countries per region (2014)

Output 1.2 Knowledge of trade-offs between food and non-food uses of dryland cereal multipurpose varieties and hybrids

Alternative uses of dryland cereals create new opportunities that have potential to increase market demand and income for smallholder farmers. During the last two decades, new sources of demand for sorghum and pearl millet have been emerging from various sectors. The demand for sorghum and pearl millet as poultry feed (especially as layer feed) and animal feed has greatly increased. Dayakar Rao, Reddy, and Seetharama (2007) projected that by the year 2010, the likely demand for sorghum for poultry and cattle feed would be around 3 million metric tons. The demand barley as animal feed in some counties in North Africa, Ethiopia and Yemen is also on the rise. Additionally, there is a growing demand for the grain of these three crops from the ethanol industry for manufacture of potable alcohol.

The main thrust of this Project is to provide poor dryland households with the technologies, linkages, and development impetus they need to harness the "pull" of these growing markets. One such trend is increasing global demand for livestock products (meat, milk) with growing global affluence (Delgado et al. 1999), which in turn leads to increased demand for grains as feed creating derived demand. The increasing demand for livestock products will overstretch corn supplies, and therefore accelerate demand from sorghum and millets for livestock feeds. The growing demand for livestock products can either be met through imports or increased domestic production. Thus there will be an increased demand for animal feeds such as crop residues, forage and feed concentrate such as grains and oil cakes (McKinsey 1997). This strong demand is increasing the market value of dryland crop residues. Recent efforts by ICRISAT in India have emphasized the development of this market demand to further "pull" demand for sorghum, increasing the income benefits received by farmers. Knowledge of farmers and other end users will be enhanced relating to 1) the varieties/hybrids incorporating the quality attributes preferred by them for consumption or industrial use, 2) improving keeping quality of the flour and exploring health benefits and nutraceutical value, 3) exploring non-conventional uses and extrusion products, and 4) nutritional value.

Methodology

Review of key non-food uses in region/country for target crops

ICRISAT and ICARDA will make an inventory of studies conducted on the key non-food uses of target crops in the region/country. The systematic review would synthesize the available information and assess the future outlook for increasing the demand and expanding market opportunities for alternative uses of sorghum, barley and pearl millet with special reference to alternative novel food products, livestock feed, starch and brewing/distilling industries. Based on review of key non-food uses, market supply and demand projections would be generated for selected crops in the targeted region/country. This exercise would also help in prioritization of potential non-food uses of the targeted crops. Similarly, it would also help in assessing the constraint analysis for different non-feed uses for selected crops, and in generating comparative assessment of profitability among different alternative uses for target crops. The entire process would assess existing and improved sorghum and pearl millet cultivars and hybrids for their suitability in different alternative uses. A thorough review would identify potential players and opportunities for stimulating the institutional alliances among public, private, industry, and NGO sectors to enhance alternative uses and market demand.

Sub-sector analysis for selected non-feed uses (poultry, livestock)

As indicated by various studies and researchers, sorghum and pearl millet have diverse uses in the non-feed sector in India. Recent studies conducted by ICRISAT have identified that nearly 30-40 per cent of sorghum and 50-60 per cent pearl millet production in the country was utilized by non-food purposes. These preliminary results generated from above output will be used in identification of major non-feed sub-sectors in the market respectively for sorghum and pearl millet. Each identified major sub-sector for each selected crop will be studied thoroughly and systematically. A representative sampling procedure will be designed by incorporating a sizable proportion of all stakeholders involved in that particular sub-sector. Primary data will be collected through pre-tested questionnaires from all stakeholders. The data will be analyzed with appropriate statistical tools and techniques. The costs and returns from different sub-sectors will be calculated based on the primary data and would be compared among different sub-sectors. Similarly, the producer farmer costs and returns per ha will be calculated under different sub-sectors. Ultimately, the producer share in the total profitability would be generated among alternative uses and sectors. The extent of value-addition among different sub-sectors will be analyzed. The entire process would also obtain the preferred traits and qualities by each sub-sector, which will help in generating new cultivars/hybrids by research organizations/institutes.

Willingness to pay for hybrid seed in WCA region

Several studies on the structure, conduct and performance of seed markets in West and Central Africa showed that the private sector is keen to enter the seed industry particularly for crops such as sorghum and pearl millet. The informal seed system remains the major supplier of sorghum and pearl millet seed to smallholder farmers (Ndjeunga, 2002, Venkatesan 1994). This is explained by the fact that seed demand for such crops is unknown and there is little apparent potential for profits. Farmers can save their own seed from past harvests without replacement and can only participate in the market when they face seed losses due to abiotic and biotic stresses or they want to experiment new varieties. In such circumstances, the private sector cannot face the variable demand for seed and therefore cannot entry the OPV sorghum and pearl millet seed markets. Various CBOs are being tested but are not sustainable because they are not driven by the private sector.

The development of sorghum and pearl millet hybrids offers several opportunities for the development of the seed industry and its sustainability. With hybrids, smallholder farmers will get more yields but will not be able to replant the seed. However, the private sector may be willing to enter hybrid seed industry because they can capture profits and there is a relatively predictable seed demand.

There is currently no market for sorghum and pearl millet hybrid seed in West Africa and there are doubts that farmers will demand for such seed. There is therefore a need to assess the willingness to pay (WTP) for hybrid seed by farmers and the factors driving the WTP. Contingent valuation method (CVM) is used to value a wider range of non-market goods and services. It involves directly asking people, in a survey, how much they would be willing to pay for specific goods. Several methods are available such as 1) directly asking consumers to state their willingness to pay using an open-ended question format, 2) a Choice-Based Conjoint Analysis, which calculates willingness to pay based on consumers' choices among several product alternatives and a "none" choice option, or 3) the Becker, DeGroot and Marschak (BDM) approach, in which the participants are obligated to purchase a product if the price drawn from a lottery is less than or equal to his or her stated willingness to pay in response to a direct question.

Milestones

- Identification of key non-food uses in region/country for target crops (2012)
- Completed analysis of 1 subsector in each region (2013)
- Completed analysis of willingness to pay for hybrid seed in Nigeria and Niger (2014)

Output 1.3 Evidence for policy and regulations to increase demand and supply of dryland cereal grain and processed products

The technological options in the coarse cereals have been quite attractive and promise good productivity generating sizeable marketable surplus. Prices and market infrastructure act as major bottlenecks in the growth of these crops. It is therefore natural that growth has stunted in the absence of proper price incentives. Given the facts that the productivity growth is satisfactory, the consumption requirements are more or less stabilized. The external demand-pull will alone exert pressure on adoption of technology. As there is a sizeable marketable surplus existing, we strongly believe that dryland cereals can be utilized to strengthen the food security system at the local level, because: (i) the dryland cereals form the dominant component of the food grain consumption in the drought-prone areas; (ii) technology has a good promise for this group of crops; (iii) there is a sizeable marketable surplus existing which can be used locally for providing food security to the landless rural poor; (iv) most of the rural households either depend on house hold production or the market for their requirements; and (v) given some price incentive these crops can do as well as any other crop. Farmers are more concerned about the prices received for the crop and they do sell some portion of their marketable surplus. Minimum Support Price (MSP) mechanism has not been effective in this respect as the marketing of the produce is not in bulk and most of the time only in local markets. In addition to MSP, there should be backing through actual and active procurement by the relevant agencies, for example in the case of India FCI and/or the Dept of Food and Civil Supplies. Mere announcement of MSP does not benefit any smallholder farmer, unless the dryland cereals are actually procured at the predetermined prices. These crops have received unfair treatment on the price front.

Though there has been productivity enhancement, due to lack of economic incentives and effective demand farmers reduced area under course cereals by shifting to other crops to earn their livelihoods. While sorghum, barley and pearl millet can substantially contribute to food, nutritional and economic security of small and marginal farmers, to stimulate demand for all the three crops, value addition at micro and macro levels with technological support and market led extension through food science and nutrition is crucial. Further, publishing evidence-based policy briefs and advocating policy and institutional changes are required to promote demand and supply of dryland cereals and products that benefit smallholder farm households, as well as for the urban poor.

Methodology

Ex-ante *impact analysis using IMPACT model*

The International Model for Policy Analysis and Commodity Trade (IMPACT) model offers a methodology for analyzing baseline and alternative scenarios for global food demand, supply, trade, income and population. The model can also be used to assess the impact of climate change on dryland cereal production and its impact on price, income and food security. The model simulates the behavior of a competitive world agricultural market for crops and livestock, and is specified as a set of food producing units (FPU) that can be aggregated to countries or regional sub-models, within each of which supply, demand and market clearing prices for agricultural commodities are generated for each year. The country and regional agricultural sub-models are linked through trade in a non-spatial way, such that the effect on country-level production, consumption and commodity prices is captured through net trade flows in global agricultural markets. Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. World agricultural commodity prices are determined annually at levels that clear international markets. The model uses a system of linear and nonlinear equations to approximate the underlying production and demand relationships, and is parameterized with country-level elasticities of supply and demand (Rosegrant et al., 2008).

In addition, we will review and analyze the existing policies in order to identify the deficiencies that constrain the demand and supply of dryland cereals and also prepare evidence-based policy briefs.

PAM to measure competitiveness of dryland cereals

The Policy Analysis Matrix (PAM), a computational framework developed by Monke and Pearson (1989), will be used to assess efficiency and competitiveness of dryland cereal production in the regions. PAM measures the profitability at both private (actual market) and social (efficiency) prices. The measure of private profitability demonstrates the competitiveness of the dryland cereals, given the current technologies, prices for inputs and outputs and policy at current market prices whereas the social profits reflect social opportunity costs. A positive social profit indicates that the country uses scarce resources efficiently and has a static comparative advantage in the production of that commodity at margin. Negative social profits indicate that a sector cannot sustain its current output without assistance from the Government, resulting waste of resource. . Three important measures viz., Nominal Protection Coefficient, Effective Protection Coefficient (EPC) and Domestic resource cost (DRC) are analyzed and compared from the PAM framework. These indicators will provide the measure of competiveness and the economic efficiency of existing systems and impact of policies on those systems.

Milestones

- Outlook Report for dryland cereals for each region (2012)
- One Policy Brief for each region disseminated to policy makers (2013)
- Measure the efficiency and competitiveness of dryland cereals (2014)

Partners and Their Roles

Key partners for Strategic Objective 1 include counterpart groups engaged in agricultural research and development monitoring, evaluation and impact assessment. Experts from a variety of disciplines are needed to effectively undertake a participatory process involving stakeholders and users. Partners with competencies in the use of new tools, including GIS and spatial analysis, as well as data management and warehousing will be needed for the analysis, synthesis, documentation and dissemination of data and information. Major research and/or development partners with specific competencies in socioeconomic and policy analysis will also be involved. At this point, the following partnerships are envisioned:

- M&E groups and socioeconomic departments of national agricultural research organizations, including ICAR in India, IAR and LCRI in Nigeria, IER in Mali, ISRA in Senegal, INRAN in Niger, INERA in Burkina Faso, and various NARES in ESA where dryland cereals are major sources of livelihood for millions of poor smallholders will be heavily involved in Strategic Objective 1. Their roles will include: identification of clusters of villages for implementing project activities; identification of key players in the value chain; baseline data collection; primary data collection and surveys relating to proposed interventions; inputting and validation of data; monitoring and evaluation coordination with private players regarding market linkages; and conducting and coordinating training programs on good agricultural practices, value addition, income-generating activities and the empowerment of women farmers. Such groups and organizations will take the lead in their respective countries, with harmonization of procedural frameworks and data aggregation being done at the regional and CRP level primarily by ICRISAT and ICARDA;
- Advanced research institutions and universities, such as IRD/CIRAD (France), ACIAR (Australia), Purdue University and the University of Florida – Gainsville (USA) will be engaged to help establish and/or adjust research priorities, analyze aggregated data and information, and assess impacts and policy implications;
- National seed regulatory agencies in target countries and regions will be engaged relative to developing and promoting evidence-based varietal release, seed system and phytosanitary

policies (output 1.3), all with an eye towards ensuring seed quality and commercialization of new dryland cereal varieties and hybrids;

- Public and private seed companies that can provide unique perspectives as well as data on dryland seed production, sales and marketing will be involved in producing all three outputs. They are well placed to validate data and information gathered under outputs 1.1 and 1.2, and have a strong interest in helping shape evidence-based see policies in our target countries;
- Gender experts and practitioners in international and national organizations, such as partner CGIAR centers and organizations, FAO and other UN Agencies, and an array of rural development NGOs will be brought on board to help design, and in many cases implement, gender-sensitive data gathering tools and processes and ensure the validity of results obtained for outputs 1.1 and 1.2, as well as help formulate, evaluate and promote gender-responsive policies;
- Local NGOs, financial institutions, farmers' organizations and agricultural marketing agencies and firms in dryland areas will engage in capacity building and implementation of Strategic Objective 1 (mainly output 1.1), including exploration of options for development programs, market linkages, contract farming, value addition, crop insurance and so on; and
- National agro-industries and private firms involved in dryland cereals processing and marketing, most of which are listed under Strategic Objectives 2 and 3, will assist in shaping research priorities related to output 1.1, and contribute their ideas and perspectives relative to policy recommendation (output 1.3).

STRATEGIC OBJECTIVE 2 - ENHANCING THE AVAILABILITY AND USE OF GENETIC DIVERSITY, GENOMICS AND INFORMATICS TO ENHANCE THE EFFICIENCY OF DRYLAND CEREAL IMPROVEMENT

Outputs, Methodology and Milestones

Output 2.1 Dynamic dryland cereal germplasm conservation, exchange and utilization

Output 2.1 focuses on the status of existing germplasm collections and related data of DRYLAND CEREALS (barley, finger millet, pearl millet and sorghum) and their exchange among the principal partners of CRP 3.6, national, regional and international research institutes, NARES, public and private sector seed companies, NGOs, farmers and other individuals to enrich the existing collections globally. ICRISAT and ICARDA gene banks conserve large germplasm collections of sorghum, pearl millet, finger millet and barley accessions from many countries (Table 4-1). Best practices will be applied to ensure long-term conservation, proper regeneration and multiplication, and characterization of these DRYLAND CEREAL genetic resources.

These collections contain much of the genetic diversity that forms the basis of future breeding efforts in these crops, as well as genes for traits of importance to other crops. However, for the dryland cereals, most of wild genetic diversity has been left untouched. Wild relatives growing in the center of origin/diversity often have the adaptive mechanisms to withstand ever-changing climatic conditions, while those in regions far from such centers of origin have adapted to otherwise uncommon conditions for the cultigen. To enrich the existing global gene bank collections, a critical assessment of present collections for diversity gaps is required. Based on these assessments, germplasm collection missions in priority areas will be required to fill identified gaps. Further, the acquisition of trait-specific germplasm, more extensive molecular characterization of existing accessions, development of representative subsets, and provision of all information as global public goods are critical to enable the use of the diversity contained in the collections.

Table 4-1. ICRISAT and ICARDA germplasm collections of sorghum, pearl millet, finger millet and barley accessions

Crop	No. of countries	No. of accessions
Barley	90	55,000
Finger millet	24	5,957*
Pearl millet	50	22,211*
Sorghum	92	37,949*

*** Including wild relatives; core and mini core sets available**

Methodology

Conserving and distributing genetic resources

Historically, the CGIAR Center gene banks have established effective and high-quality management procedures for the safe conservation, maintenance and distribution of the genetic resources under their supervision. During the past several years, the Global Public Goods (GPG) projects funded by the CGIAR have allowed the gene banks to upgrade many of their facilities, enhance the collections where possible and increase the information available on the collections. Recently, efforts by the Global Crop Diversity Trust (GCDT) are targeting long-term funding for the core gene bank operations, and are providing opportunities for joint discussions and planning of global crop collections. Under this Output, the partners will work together to establish gene bank operations at international standards The existing DRYLAND CEREALS collections will be maintained using the best practices of conservation, regeneration/multiplication and documentation, mainly through the development of crop registries to reduce duplications, and the proper handling of wild species for maintaining their genetic integrity during the regeneration and multiplication cycles. All accessions from the CGIAR gene banks will be distributed under the agreed-upon SMTA, as is current practice.

Enriching the collections with missing diversity

Gap analysis refers to a systematic method of analyzing the degree of conservation of taxa, in order to identify those locations, taxa and particular traits not secured or under-secured in conservation systems (Maxted et al. 2008). Gap analysis will be done by application of FloraMap, DIVA-GIS and other GIS computer packages to identify the gaps in collections. Such analyses will be performed in terms of representation of species, of populations within species, of land/ecological conditions sampled so far. Special GIS-facilitated approaches will be developed to permit targeting germplasm with specific adaptive traits during collection missions. Partners to the Treaty will jointly identify the gaps in all DRYLAND CEREALS germplasm collections and launch germplasm collection missions. The CRP approach will minimize duplication of collections, and the planning and conducting of collection missions in each target crop/region/country.

Providing global access to genetic resources and related information

Traditionally, passport and characterization data on the accessions have been made available via information systems at each Center and/or via global systems such as SINGER (http://singer.cgiar.org/). GrinGlobal (Cyr et al., 2009) is being developed by the USDA, GCDT and Bioversity as a more robust gene bank management and information system. CRP 3.6 partners plan to evaluate GrinGlobal, and if feasible, implement it as a global DRYLAND CEREALS information system. The information on the collections will be updated, particularly for location data (latitude and longitude) of collection sites.

Enabling better use of genetic resource collections

In the case of the CGIAR gene banks, the size of the entire germplasm collections are too large to conduct multi-location evaluation of germplasm for traits of economic importance such as yield, resistance to biotic and abiotic stresses, traits related to quality and to adaptation, which often show high genotype x environment interactions. Hence, to carry out meaningful evaluations, the large collections must be sub-sampled to bring the size of the sets of materials evaluated to a manageable level, as suggested by Frankel and Brown (1984). Core (10% of entire collection), mini-core (1% of entire collection) and reference sets (approximately 300 accessions selected based on optimal molecular diversity) provide useful sub-sets of the global genetic diversity for each crop, and are the material of choice for studying global diversity and assessing donors of genes and alleles (Caniato et al. 2011). Such sub-sets have been jointly developed by CIRAD and ICRISAT for sorghum, by ICRISAT for finger millet, pearl millet and sorghum (Upadhyaya et al. 2009b, 2010, 2011) and by ICARDA for barley http://generationcp.org (GCP 2008). These represent the diversity available within ICRISAT's and ICARDA's current germplasm collections, but will be enhanced under CRP 3.6 by including germplasm from other partners.

Reference sets and minicore collections have been used in several crops to identify trait-specific germplasm for use by the breeders (summarized in Upadhyaya et al. 2009a). Similarly, the sorghum reference set has been exploited to identify superior sources of tolerance to high levels of aluminum saturation (Caniato et al. 2011). Focused Identification of Germplasm Strategies (FIGS) will be used to better target sought traits in subsets with manageable size. The principle of the FIGS approach is to use agro-climatic information, generated by Geographic Information Systems, or other types of information, to describe the environments from which genetic resources were originally collected. This in turn gives a rational basis upon which to select best-bet subsets from global plant genetic resource collections that will maximize the chances of finding the desired traits in a manageable set of genotypes and thus greatly enhancing the efficiency and timeline associated with gene discovery (Bhullar et al., 2009; El-Bouhssini et al., 2009, 2010). Algorithms will be developed to select subsets with high probability of finding adaptive sought traits (Mackay and Street 2004; Endresen et al. 2011). Selected subsets developed via these different strategies will be multiplied, information provided on-line, and seed and DNA made globally available to provide scientists with easier access to the breadth of diversity represented in the entire collections. By screening such reduced but diverse sets, scientists can maximize the probability of finding appropriate entry points to global germplasm collections when seeking useful diversity for research and breeding programs.

Barley, finger millet and sorghum are seed-propagated and largely self-pollinated, which allows ready use of their mini-core and reference sets of uniform pure line accessions in linkage disequilibrium (LD) mapping studies to identify associations of DNA sequence variation with trait variation. However, this is much more difficult with cross-pollinated seed-propagated species such as pearl millet as most of the genetic variation in such species is found within accessions. There, development of an inbred association panel, having most of the genetic variation distributed between accessions, would make it substantially easier to apply LD mapping methods to pearl millet.

Milestones

- Location data (latitude and longitude) updated for all DRYLAND CEREAL accessions in ICARDA and ICRISAT genebanks (2012)
- GRIN-Global implemented as a global DRYLAND CEREAL management and information resource (2012)
- Mini core, reference and/or FIGS sets of DRYLAND provided to partners for evaluation in stressful environments and assessment of quality traits (2012)
- Reference sets and minicore collections of DRYLAND CEREALS updated (2013)
- Crop registries for DRYLAND CEREALS genetic resources developed and gaps in existing *ex-situ* germplasm collections of barley, finger millet, pearl millet and sorghum identified (2013)
- DRYLAND CEREAL germplasm collection missions completed in priority areas in Africa and Asia to fill gaps and to collect trait-specific germplasm (2013)
- Pearl millet inbred germplasm association panel developed, conserved and available for dissemination (2014)

Output 2.2. Characterized dryland cereal genetic resources for key traits and future use

This output will efficiently deliver novel sources of genetic variation to enhance productivity, production stability, and product quality of grain and crop residues from DRYLAND CEREALS. Exploiting existing germplasm resources, new approaches to identifying the genes underlying phenotypic variation (including TILLING and Eco-TILLING), will focus on traits having the greatest potential to enhance DRYLAND CEREAL performance across sites and years as identified by crop modeling (Hammer et al. 2006). For example, more effective phenotyping of barley, pearl millet, and sorghum for adaptation to low soil phosphorous is needed as field heterogeneity frustrates these efforts. Geo-spatial analysis of past and on-going phenotyping studies in West Africa (with McKnight Foundation and BMZ support) will be used to design more effective evaluation methods. Rainout-shelter lysimetric pot testing methods, developed at ICRISAT-India, are being evaluated at ICRISAT-Niger for pearl millet and sorghum. Hydroponics-based Al-toxicity screening is to be installed at ICRISAT-Mali. Controlled-environment and on-station field results will need to be validated with on-farm testing. Sharing experiences of abiotic stress testing from different ecological zones within (Sahelian zone and Sudanian zone studies in West Africa) and between regions, and across DRYLAND CEREALS will stimulate and enhance our efforts.

Methodology
Identifying novel diversity

While the existing genetic resources collections and breeding populations of DRYLAND CEREALS contain a large amount of genetic diversity, new methods are available to create additional diversity and/or screen existing diversity more efficiently. TILLING (McCallum et al. 2000) uses chemical mutagenesis to produce allelic series of point mutations for virtually all genes; and such allelic series can be used to efficiently determine the functions of individual genes. The process involves first identifying DNA sequence variants (alleles) for a particular gene from the population of point mutations, and then comparing the phenotypes associated with different alleles. TILLING is of particular value for essential genes where sub-lethal alleles are required for phenotypic analysis. TILLING populations are currently available for barley, pearl millet and sorghum (Xin et al. 2009). Where these are not available in the Center's collections, seed will be obtained, increased and placed in the germplasm collection. DNA samples will be taken to provide ready access for screening for unique phenotypes. A related methodology, Eco-TILLING, uses the high-throughput mutation detection methods of TILLING to seek naturally occurring variants in specific genes using sets of genetically diverse germplasm accessions (e.g. Mejlhede et al. 2006). The reference collection sets mentioned above will serve as excellent Eco-TILLING resources. DNA samples will be extracted from all reference collection entries, pooled, and these DNA pools made available, along with seed, for screening for unique alleles and phenotypes. As available, the DNA sets will be screened with candidate gene sequences to identify sequence variants determine possible phenotypes based on altered genotypes at the candidate gene loci. Initial target genes will include key abiotic stress tolerance, disease resistance and end-use quality genes.

Identifying traits of value for targeted improvement

Before characterizing mini-cores, reference sets, and TILLING population progenies of DRYLAND CEREALS for a range of traits potentially related to yield performance under stress conditions, it is critical to undertake detailed physiological examinations of traits and mechanisms of plant adaptation to stress and constraints on these. This is particularly the case for tolerance to complex abiotic constraints such as drought. Recent research indicates that specific traits, like limiting plant water use under non-stress conditions, can be particularly important (Kholova et al. 2010 a, b; Vadez et al. 2011a). After identifying such traits, crop simulation modeling will be used to test their effects on yield across a range of environments and weather conditions. This follows recent work demonstrating the proof-of-concept and value of this approach (Hammer et al. 2006), in which it was demonstrated that crop ideotypes with different leaf area indices are adapted to specific rainfall conditions. In another study, Sinclair et al. (2010) showed the criticality of several traits for soybean yields across years and environments (e.g. transpiration sensitivity to VPD), and the limited importance or negative effects of others (e.g. speed of root growth), providing a stochastic assessment of the value of each of these traits to help breeders more effectively improve adaptation and yield performance. Once critical traits are identified in each crop, i.e. those traits and mechanisms related with drought adaptation under specific conditions and that are proven to have a yield benefit in a majority of the years in a relevant number of locations, diversity for these traits will be sought (initially from minicore, reference, or FIGS sets) for subsequent inclusion in breeding programs. A particular focus in these activities will also be to explore the traits related to adaptation to changes in the climatic conditions (Vadez et al. 2011b). Here also, a similar approach will be taken with crop simulation modeling being used to estimate the value of specific traits/mechanisms before seeking variants for these.

Refining high-throughput phenotyping procedures

Improved methods now in use to assess abiotic stress tolerance have been described at length in recent publications (Vadez et al. 2007a, 2008, 2011a, 2011b; Zaman-Allah et al. 2011a, 2011b; Kholova et al. 2010a, 2010b, 2011; Ratnakumar et al. 2009; Bhatanagar-Mathur et al. 2007, 2008, 2009a, 2009b). Our approach will be to tackle traits and mechanisms that are believed to contribute to the adaptation of DRYLAND CEREALS to the most important abiotic stresses. For the case of drought, two areas of work will be followed, one assessing the contribution of roots, the other one focusing on the control of plant water use. The work on roots will use a large lysimetric facility recently developed at ICRISAT (http://www.icrisat.org/bt-root-research.htm), which allows assessment of the functionality of root systems and their contributions to drought adaptation. Compared to previous platforms, this facility allows a much higher throughput for investigate rooting traits and provides much more informative data on the role of roots. Such data are sometimes counterintuitive, but can then prove critical to making breakthroughs in drought tolerance improvement (e.g. Zaman-Allah et al. 2011a, 2011b; Ratnakumar et al. 2009). For the control of water use, several high throughput protocols are described in the above mentioned publications that essentially focus on leaf conductance, conductance response to vapor pressure deficit (VPD) (Kholova et al. 2010b), leaf development aspects (Kholova et al. 2011), and transpiration response to soil drying (Kholova et al. 2010a). Protocols for the assessment of salinity tolerance at large scale are also routinely used (Vadez et al. 2007b, 2011c; Krishnamurthy et al. 2011), along with those for low P tolerance (Valluru et al. 2009; Karanam and Vadez 2010). However, methods for assessing heat tolerance need to be improved.

While effective protocols have been developed to identify sources of resistance to major insect pests (Sharma et al. 2003) and diseases (Singh et al. 1993, 1997; Thakur et al. 2007), there is a need to refine screening techniques for emerging pests and diseases such as aphids in sorghum and blast in pearl millet and finger millet, including the use of molecular techniques to identify diverse sources of resistance to key pests. Sources of resistance have been identified against key insect pests and diseases, but there is a continuing need to identify new sources of resistance for diseases such as downy mildew in pearl millet, blast in finger millet, and rusts in barley, and sources with higher levels of resistance to shoot flies and stem borers (Sharma et al. 2003; Thakur et al. 2009). The material will be screened in hot spot locations and/or under artificial infestation/inoculation in the greenhouse and in the field to identify new sources of resistance and to phenotype segregating pre-breeding materials and mapping populations for identification of resistance (and QTLs or major genes controlling them) for subsequent introgression into high yielding cultivars in Strategic Objective 3. The identified sources and improved cultivars will be tested across locations for stability of resistance and to identify/monitor evolution of virulent strains of diseases and/or insect pests.

Obtaining genome-wide genotypic information

An assembled whole-genome sequence of a crop species greatly facilitates exploitation of genetic information gained from better-studied model systems like Arabidopsis, Medicago, and rice. A nearly complete aligned genome sequence of sorghum is available (Paterson et al. 2009), but the larger genomes of other DRYLAND CEREALS have not yet been sequenced. Sequencing the gene space at a fraction of the cost of a whole genome sequence would be beneficial, but would likely miss many regulatory regions and the thin scattering of genes in regions distant from gene-rich distal ends of chromosome arms. Near-complete aligned genome sequences of barley, finger millet and pearl millet will be developed, and followed up with re-sequencing efforts for a modest number of genetically diverse wild and cultivated accessions, to identify the most common alleles at nearly all loci for each DRYLAND CEREAL.

Identifying trait-marker associations for more efficient breeding selection

Establishment of marker-trait associations for priority traits in each DRYLAND CEREAL greatly enhances the efficiency of pyramiding of favorable alleles at multiple loci contributing to abiotic stress tolerance, biotic stress resistance, and enhanced yield and product quality in elite genetic backgrounds (Varshney and Dubey 2009). Using conventional bi-parental mapping populations, multi-parent advanced generation intercross populations (MacKay and Powell 2007), and association panels including introgression lines generated by backcrossing (Jordan et al. 2011), high throughput phenotyping, and high-density haplotype data sets such as those produced using genotyping-by-sequencing (GBS) approaches (Elshire et al. 2011), we will identify and validate marker-trait associations for genes and quantitative trait loci contributing to priority traits for all DRYLAND CEREALS. Proof-of-concept studies will be conducted with sorghum (which has the best genomic tools among dryland cereals), and the best approaches will then be implemented in barley, pearl millet and finger millet as well.

Milestones

- Re-sequencing and genotyping-by-sequencing (GBS) approaches identify >1 M single nucleotide polymorphism (SNP) markers in sorghum (2012)
- Publically available DRYLAND CEREAL association panels, TILLING populations, MAGIC populations and bi-parental mapping populations inventoried, priorities for their assembly in ICARDA and ICRISAT gene banks determined, and likely costs for their assembly estimated (2012)
- Phenotyping network established for DRYLAND CEREALS across partners and crops (2012)
- Effective field phenotyping methods for adaptation to low-P identified (2013)
- Sorghum backcross nested association mapping (BCNAM) populations available for evaluation in genetic backgrounds for two production systems in WCA (2013)
- Recessively inherited genetic male-sterility backcrossed (to BC1) into backgrounds of at least 5 genetic genetically diverse, agronomically elite cultivars of barley, finger millet and sorghum for each priority target production system as tool for genetic diversification (2013)
- High-throughput phenotyping platform, including imaging facility (infra-red and RGB imaging), based on existing lysimeter facility established at ICRISAT-India (2014)
- Draft genome sequences produced for additional DRYLAND CEREALS (2014)
- Protocols to screen for resistance to blast in finger and pearl millet, and aphids in sorghum refined and shared with NARS; and protocols to screen barley for resistance to barley gall midge established (2014)
- At least ten new sources of resistance to downy mildew, blast, and head miner in pearl millet; grain molds, foliar diseases, shoot fly, and aphids in sorghum; major diseases and insect pests in barley, and blast in finger millet identified and distributed to NARS (2014)

- Mini core and reference collections of pearl millet, sorghum, and finger millet evaluated against key biotic and abiotic stresses and for quality traits (2014)

Output 2.3. Modern genomic and information-based platform for more efficient and integrated breeding

The power of genomics, up-to-date information technology, and systems biology enable large increases in the efficiency of dryland cereal research and breeding efforts globally. This is motivated largely by the revolution in the biological sciences brought by genomics and information technology, and offers a ‘window’ for the entire CRP to exploit new opportunities through advanced science. DNA sequencing technologies, for example, have evolved to the point where ‘personalized’ genomics is now possible and very high density haplotype fingerprinting (Elshire et al. 2011) is becoming practical for genome-wide association studies. Thus, sequencing the genomes of dryland cereals would not only be a reasonable proposition but also an imperative if we are to fully capitalize on developments in molecular biology. The full power of marker-assisted selection – from simple backcrossing of single-gene value-addition traits into popular DRYLAND CEREAL cultivars to genome-wide selection in rapid-cycling breeding populations – can be exploited more effectively as next generation sequencing (NGS) technologies and associated data analytical platforms drive down the costs of marker-data generation and management.

Coupled with this is the urgent need to use information technology and bioinformatics to provide crop breeding programs a centralized and functional portal to access information and analytical tools, as well as the services that enable use of genomic-level information efficiently (a good example of such a portal is the Integrated Breeding Platform (IBP) from the Generation Challenge Program). Such integrated portals should also incorporate geo-spatial information, genetic resource mapping and the characterization of different agro-ecological and crop utilization options or domains present in dryland farming systems, especially the sites of intervention for dryland farming systems as identified in CRP 1.1. The most efficient way to achieve this will be to build on the IBP being developed by the Generation Challenge Program. The IBP’s goal is to serve as a one-stop shop providing access to modern tools, applications, and services for integrated breeding. The vision, as part of the CGIAR redesign, is to have the IBP operate as a crosscutting platform that will service the needs of all CRPs. Thus this portal will serve many of the needs outlined above, and additional needs more specific to CRP 3.6 could be added to it as needed.

This output is an ambitious but necessary undertaking if the partners are to meet the urgent need to more effectively mine genetic diversity from germplasm collections, broaden the genetic base of breeding populations using primary, secondary and tertiary gene pools, increase abiotic tolerances and biotic stress resistances, and expand research on and utilization of DRYLAND CEREAL species.

Methodology

Exploiting new information technology capabilities

New information technology capabilities enable efficient documentation and utilization of breeding data for dryland cereals. Utilization of these capabilities by large plant breeding companies is advanced, but application for dryland cereals is lagging and very uneven. Strengthening data management capacities for dryland cereal breeding is essential, and will increase value of ongoing and previous research investments.

Developing, promoting, and integrating marker-assisted breeding methods

Molecular markers including diagnostic and/or functional markers are now available for many traits that underlie abiotic and biotic stress tolerance in barley, pearl millet and sorghum. While many markers for quantitative trait loci (QTLs) have been published, limited numbers are actually deployed in breeding. The challenge for breeders is how to integrate marker systems with phenotypic selection to enhance the rate and cost-effectiveness of creating of new parental lines and target genotypes. Strategies for efficient pyramiding of alleles at multiple quantitative trait loci will be implemented including the use of marker-assisted recurrent selection (MARS), marker-assisted population improvement (MAPI), and genome-wide selection (GWS) to accumulate desirable alleles for complexly inherited traits. Modern breeding platforms that integrate genetic, genomic, and phenotypic information have the potential to accelerate plant-breeding progress. Thus, it is imperative that conventional and molecular breeding approaches are better integrated and implemented for more effective improvement of complex traits in productive, adapted backgrounds. To achieve this objective the GCP is coordinating with a broad set of partners, including CGIAR Centers and NARS the development of an Integrated Breeding Platform (IBP). This platform is envisioned as a sustainable, web-based, one-stop-shop for information, analytical tools, data management and related services to design and carry out integrated breeding projects and boost crop productivity and resilience for smallholders in drought-prone environments by exploiting the economies of scale afforded by collective access to cutting-edge breeding technologies and informatics hitherto unavailable to developing country breeders.

Milestones

- Analysis pipeline for genotyping-by-sequencing data implemented at ICRISAT (2012)
- New marker-based breeding projects initiated with national breeding programs and links with Integrated Breeding Platform facilities established (2013)
- Marker-assisted recurrent selection (MARS) demonstrated in sorghum (2013)
- Genome-wide selection (GWS) method evaluated for at least for one trait in each DRYLAND CEREAL crop (2014)
- Marker-assisted population improvement (MAPI) demonstrated in pearl millet (2014)

Partners and their roles

A large number of specific partners have been identified for participation in producing the outputs associated with Strategic Objective 2:

- ICARDA and ICRISAT will contribute to output 2.1 by conserving and distributing genetic resources, establishing crop registries for and identifying and filling gaps in existent *ex-situ* collections of barley, finger millet, pearl millet and sorghum and their wild relatives, and enhancing genebank information and information access (implementing GRIN-Global), as well as refining and disseminating mini-core and reference germplasm sets of these cereals;
- ICARDA will contribute to Output 2.2 by exploring use of barley TILLING population and Eco-TILLING using the barley reference germplasm set; identifying traits of value for targeted improvement of abiotic stress tolerance and assessing their potential utility via crop simulation modeling; enhancing phenotyping facilities and refining screening protocols; coordinating mini-core and reference set characterization to establish marker/gene-trait associations and identify entry points to the larger germplasm collections for specific target traits related to yield, yield stability and product quality; developing and using high density genetic fingerprinting methods combined with high quality phenotyping data sets to establish marker/gene-trait associations; and allele mining and pre-breeding efforts to bring favorable alleles for high priority traits from diverse un-adapted germplasm into locally-adapted backgrounds to facilitate their wider use in breeding programs;
- ICRISAT will contribute to Output 2.2 by exploring use of the new pearl millet TILLING population and Eco-TILLING using the sorghum reference germplasm set; identifying traits of value for targeted improvement of abiotic stress tolerance and assessing their potential utility via crop simulation modeling; enhancing phenotyping facilities and refining screening protocols; coordinating mini-core and reference set characterization to establish marker/gene-trait associations and identify entry points to the larger germplasm collections

for specific target traits related to yield, yield stability and product quality; instigating development of nearly complete aligned genome sequences of finger millet and pearl millet, and contributing to sorghum re-sequencing efforts to establish SNP-based haplotype maps; developing and using high density genetic fingerprinting methods combined with high quality phenotyping data sets to establish marker/gene-trait associations; and allele mining and pre-breeding efforts to bring favorable alleles for high priority traits from diverse un-adapted germplasm into locally-adapted backgrounds to facilitate their wider use in breeding programs;

- ICARDA and ICRISAT will contribute to Output 2.3 by exploiting new information technology capabilities to improve the efficiency of documentation and utilization of breeding data; and developing, promoting and integrating marker-assisted breeding methods with links to the GCP's Integrated Breeding Platform to improve efficiency of regional and national breeding programs;
- The Indian Council of Agricultural Research (ICAR) and its affiliates will contribute to Outputs 2.1, 2.2 and 2.3 in nearly all barley, finger millet, pearl millet, and sorghum activities targeting South Asia; in particular, ICAR's National Bureau of Plant Genetic Resources (NBPGR) will contribute to Outputs 2.1 and 2.2 via its efforts on germplasm assembly, exchange (import and export) and evaluation of barley, finger millet, pearl millet and sorghum germplasm mini core, reference and FIGS sets;
- Generation Challenge Program (GCP) will contribute: to output 2.1 validation of genotyping of the sorghum reference sets; to output 2.2 phenotypic assessment of the reference set, and the development of sorghum BCNAM populations that can combine genetic diversification with establishment of marker-trait associations; and to output 2.3 via the sorghum MARS project and Integrated Breeding Platform (note that, although not direct partners in Strategic Objective 2, Wageningen University, IRRI and CIMMYT are partners in the IBP and will contribute to developing its electronic field books and data analysis pipelines, while iPlant will provide the cyber-infrastructure for hosting components of the Platform);
- INTSORMIL will contribute to output 2.2 via improvements in screening methodologies for *Striga* resistance and key sorghum insect pests in WCA and ESA, and to outputs 2.2 and 2.3, in particular via post-graduate training and mid-career training of sorghum and pearl millet scientists from/for national programs in Africa;
- CIRAD will contribute to output 2.1: by characterization of the genetic diversity of sorghum and pearl millet managed *in situ* by farmers, and definition of indicators for assessing genetic diversity (FFEM-2 project); by dynamic *in situ* conservation of sorghum genetic resources through enrichment of breeding program genetic basis from a wide range of donor parents (GCP BCNAM project); and by validation of the GCP sorghum reference genotyping characterization and development of a SINGER-based portal to access DRYLAND CEREALS reference set information (GCP IBP project). CIRAD will contribute to output 2.2: by exploring sorghum genetic diversity for key quality traits for 1st and 2nd generation biofuels, and identification of sorghum genes/markers associated with stem fiber components and digestibility, sugar content, and juiciness; and by identifying favorable alleles from a wide range of donor parents for important adaptation and quality traits in sorghum (GCP BCNAM project). Relative to output 2.3, CIRAD will contribute: by implementation of the marker assisted recurrent selection (MARS) methodology with the national sorghum breeding program in Mali (GCP MARS project); and by developing genetic material with combined properties of high-resolution genetic analysis and direct breeding applications in sorghum (GCP BCNAM project)
- CIRAD/IRD will contribute to output 2.1 by new sampling and genetic characterization for sorghum, pearl millet germplasm in West Africa (ARCAD project); to output 2.2 by identifying genes/markers associated with adaptation to climate variation in sorghum and pearl millet

(ARCAD project); and to output 2.3 by developing genomic resources for pearl millet and sorghum (20,000 to 50,000 ESTs, thousands of SNPs, and resequencing) for cultivated and wild species (ARCAD project)

- Alberta Agriculture, Food and Rural Development (AAFRD) will contribute to output 2.2 by evaluating barley germplasm for disease resistance and agronomic performance;
- The Australian Center for Plant Functional Genomics will contribute to output 2.2 for barley, evaluating abiotic stress tolerance (including drought, heat and salinity tolerance) using both conventional quantitative traits and other genomic approaches, and the use of high-throughput phenotyping platforms;
- Cornell University will contribute to output 2.2: by establishing genotyping-by-sequencing (GBS) protocols for sorghum and barley; by development of the analytical pipeline for GBS data sets with and without a reference genome sequence and transfer of this pipeline to ICRISAT; and by transferring hydroponic screening protocols, establishment of gene-trait associations, and allele mining for aluminum tolerance in sorghum;
- The Department of Employment, Economic Development and Innovation (DEEDI) will contribute to output 2.2, providing guidance on sorghum BCNAM population development and exploitation as a pre-breeding method for introgressing useful genetic variability into genetic backgrounds meeting local/regional adaptation and product quality requirements (this will include the transfer of genetic-male-sterility to diverse elite backgrounds to facilitate introgression-based pre-breeding programs for self-pollinated dryland cereals (barley, finger millet and sorghum);
- EMBRAPA will contribute to output 2.2 via its involvement in establishing gene-trait associations for of aluminum tolerance and low phosphorus tolerance in sorghum and subsequent allele mining;
- The Global Crop Diversity Trust (GCDT) will contribute to output 2.1 by providing support for genebank operations, safety backup at the Svalbard Global Seed Vault in Norway, and NARS collections at ICARDA and ICRISAT;
- The Japan International Research Center for Agricultural Sciences (JIRCAS) will help with output 2.2 phenotyping to establish marker-trait associations for sorghum biological nitrification inhibition;
- The Millennium Seed Bank will contribute to output 2.1 via its conservation research on germplasm of barley, finger millet, pearl millet and sorghum wild relatives;
- The NORDIC Gene Bank (NGB) will contribute to output 2.1 by providing safety backups of barley, finger millet, pearl millet and sorghum germplasm collections at the Svalbard Global Seed Vault;
- Oregon State University (USA) will contribute to output 2.2 by molecular mapping of barley within the North America Barley Genome Mapping project and identification of molecular markers associated with resistance to barley diseases;
- The Scottish Crop Research Institute (SCRI) will contribute to output 2.2 related to genetic analysis of barley drought tolerance;
- The United States Department of Agriculture Agricultural Research Service (USDA-ARS) will contribute to output 2.1 via its role in development and implementation of the GRIN-Global crop germplasm collection database; it will also contribute to output 2.2 by developing genotyping-by-sequencing protocols and data analysis pipelines, as well as transfer of refined aluminum tolerance screening methods to ICRISAT-Mali;
- University of Adelaide, Waite Institute (Australia) will contribute to output 2.2 by joint evaluation of barley germplasm for low rainfall environments, and for salt-stressed environments;

- University of Georgia (USA) will contribute to output 2.2 sorghum re-sequencing and establishment of marker-trait associations in finger millet, pearl millet and sorghum;
- University of Hohenheim (Germany) will contribute to output 2.2 characterization of sorghum and pearl millet germplasm for adaptation to conditions of low soil P availability, and to characterization of a pearl millet inbred germplasm association panel; it will also contribute to output 2.3 exploration of the potential of marker-assisted population improvement (MAPI) in pearl millet;
- University of Kassel (Germany) will contribute to output 2.2 characterization of sorghum and pearl millet germplasm for adaptation to conditions of low soil P availability;
- University of Queensland (Australia) will contribute to output 2.2 by enhancing crop simulation models for evaluation of the utility of drought tolerance-related traits across a range of environments and weather conditions;
- University of Sydney Plant Breeding Institute (Australia) will contribute to output 2.2 by evaluation of barley germplasm for resistance to barley stripe (yellow) rust at the Cobbitty-based cereal rust research facilities;
- National programs, including NARES, LDC universities and NGOs will contribute in various ways:
    - Burkina Faso will contribute to output 2.2 by phenotyping of sorghum and pearl millet germplasm, including activities related to establishment of marker-trait associations for tolerance to low P conditions in pearl millet and sorghum, and for *Striga* resistance in pearl millet;
    - China will contribute to output 2.2 by screening barley Fusarium Head Blight nurseries in Hangzhou and Shanghai;
    - Ecuador will contribute to output 2.2 by screening barley germplasm for yellow rust resistance;
    - Ethiopia will contribute to output 2.2 by screening barley germplasm for resistance to net blotch, scald, powdery mildew, and stem rust; screening sorghum germplasm for drought tolerance and *Striga* resistance, and screening finger millet germplasm for blast resistance and drought tolerance;
    - Mali will contribute to output 2.2 activities related to establishment of marker-trait associations for tolerance to low P conditions in pearl millet and sorghum; and to output 2.3 activities related to GCP sorghum MARS and BCNAM projects linked to the Integrated Breeding Platform;
    - Morocco will contribute to output 2.2 by screening for barley stem gall and midge resistance;
    - Mexico will contribute to output 2.2 by screening barley germplasm for Fusarium head blight, yellow rust and scald;
    - Niger will contribute to output 2.2 by screening sorghum germplasm for aluminum tolerance, and development of pre-breeding populations for this trait, as well as evaluation of pearl millet germplasm for food processing traits;
    - Nigeria will contribute to output 2.2 by evaluation of sorghum germplasm for midge resistance and *Striga* resistance, and contributing to establishment of marker-trait associations for pearl millet *Striga* resistance;
    - Senegal will contribute output 2.2 activities related to establishment of marker-trait associations for tolerance to low P conditions in pearl millet and sorghum; and
    - Tunisia will screen barley for scald and BYDV resistance, contributing to Output 2.1.
- NARS, Universities and NGOs in different countries will contribute to Output 2.1 by their involvement in germplasm assembly, exchange and evaluation of sorghum, pearl millet and

finger millet germplasm (mini-core, reference and trait-specific germplasm sets including FIGS) to identify promising sources of traits for utilization in crop improvement; they will also contribute to exchange of information through publicly accessible crop information systems

STRATEGIC OBJECTIVE 3 - DEVELOPING IMPROVED DRYLAND CEREAL VARIETIES AND HYBRIDS FOR INCREASED YIELD, QUALITY AND ADAPTATION IN SMALLHOLDER FARMERS' FIELDS

Outputs and Milestones

Output 3.1. High grain and fodder yielding varieties and hybrids with desired end-user quality attributes

Dryland cereals are mostly staple crops, and thus the quantity produced, especially in poor years is an essential criterion for variety adoption. Thus breeding varieties with higher grain, straw or stover, or whole plant value productivity is the overriding goal for dryland cereal breeding programs. When targeting farm households, who mostly do not produce sufficient staple foods to last for the whole year, without many options for producing income-generating crops, it is necessary that grain or stover are produced even under the most adverse conditions. Thus yield stability is an important consideration, as well as storability of the grain, and the efficiency of preparing food from it, i.e. minimizing losses during processing, from decortication for example.

We thus plan to produce new breeding materials, parental lines, varieties or hybrids, which provide farmers with options to increase the productivity of their staple cereal crop(s) beyond what they traditionally achieve. We will use a range of methods, and will work towards improving the effectiveness and efficiency, with which productivity and its stability can be improved within the context of the targeted production systems in each region.

In production systems, where farmers tend to commercialize their dryland cereal production, the productivity goals are similar, but issues of profitability become more prominent, also in the context of the competition with other cash crops grown in the same systems. In such situations responsiveness to inputs, and superior quality, meeting market demands or preferences will be crucial.

Large genetic variability exists for a range of traits in the germplasm collections and breeding materials, and effective breeding methodologies exist to substantially improve dryland cereal yield potential. For instance, hybrids have been shown to out-yield varieties by 25-30% both in pearl millet and sorghum (Reddy et al., 2004). Consequently pearl millet and rainy season sorghum hybrids are now the predominant cultivars in India in those farming systems where serious efforts in the past were made to develop such cultivars. Similar gains through hybrid technology can be expected in these crops in the African regions as well as in the post rainy season sorghum. While pearl millet breeding efforts in SA will continue to be confined to the development of high-yielding and disease resistant hybrid parents, leaving the actual hybrid development to NARS and the private sector (as per the practice so far), ICRISAT in India will accelerate the development of hybrids for post rainy season sorghum. In finger millet and barley, genetic improvement for developing high-yielding varieties will be strengthened.

Methodology

Assembly of appropriate germplasm

In close collaboration with Strategic Objective 1 and Strategic Objective 2 we will assemble germplasm that has high chances to contain useful target traits, and the required combination of adaptation traits for specific target environments. This is particularly important for finger millet where breeding programs are still young. This is also appropriate when entering into a new target set of environments, especially if abiotic and biotic constraints can cause severe harvest losses. This approach has been successfully used in several dryland cereal breeding program targeting harsh environmental conditions (Weltzien et., 1989, Ceccarelli et al., 1991, Weltzien et al., 1997)

Pedigree breeding

This is the most widely used method for creating new experimental varieties in self-pollinated crops, like barley or sorghum. Developing inbred hybrid parents of pearl millet also relies on pedigree breeding. The method is particularly useful for introducing specific single genes into elite breeding material or lines, such as dwarfing genes or specific resistances. Trait-based breeding to develop potential hybrid parents of sorghum and pearl millet has proved useful to NARS and private sector in the SA region to broaden the genetic base of their programs and help in breeding increasingly productive hybrids as evidenced from the continuing genetic grain being made in both sorghum and pearl millet in India (Rai et al., 2006, Reddy et al., 2006) In finger millet we will evaluate different techniques for generating crosses. The success rate so far is low, and a few breeders have been relying on selection between and with landrace varieties to identify new options for farmers.

Identification genetically well differentiated, heterotic groups

Heterosis tends to manifest itself between distinct, unrelated, genetically well-differentiated groups of germplasm or breeding material. Maintaining the groups for breeding male and female parents separately tends to allow for long-term genetic gains from hybrid breeding. No hard rules exist in choosing and delineating such groups, and experience and knowledge of the breeding material tends to play an important role. With the option for conducting genome wide marker analyses at relatively low cost, using genetic distances between different groups of breeding material, or germplasm. This approach is being developed for sorghum and pearl millet in West Africa, where hybrid breeding is just beginning. The heterosis thus identified can also be exploited when developing synthetic varieties, or broad based populations (Rattunde and Clerget, 2008).

Identifying target groups of environments with similar adaptation and use requirements

The large datasets available from previous performance trials has been successfully used to identify sufficient and representative evaluation environments for effective testing of breeding materials and for collaborating with farming communities and processors of grain and stover, in order to identify priorities for variety development and seed delivery within a specific target zone or production system (Ceccarelli et al., 1996; Christinck et al., 2005; Weltzien et al., 2007; Weltzien et al., 2008a; Weltzien et al., 2008b)

Population improvement by progeny based recurrent selection

Among the dryland cereals pearl millet lends itself most easily to recurrent selection. Several milestones – varieties of pearl millet India are the result of recurrent selection in broad based populations [WCC75 (Andrews et al. 1985), ICTP 8203 (Rai et al. 1990)]. The effectiveness of single plant based, mass selection type procedures has been shown for improving local adaptation of broad based populations, and for reducing the frequency of undesirable, dominant alleles. Model calculations, based on genetic parameters estimated from progeny trials conducted largely in SA, indicated that under most circumstances the genetic gain from full-sib recurrent selection is higher than for other methods. One reason is that only two generations per selection cycle are required, and another reason is that experimental errors tend be lower, and thus heritabilities higher, when testing non-inbred progenies (Schipprack, 1993). This is specifically relevant when targeting more marginal, high stress environments. We will continue to compare these methods, especially for new traits, such as Striga resistance in pearl millet. (Schipprack, 1993; Von Brocke et al., 2008; Rattunde et al., 1997; Rattunde et al., 2009)

We are applying recurrent selection procedures also to broad based sorghum populations, built by using the ms_3-gene for male sterility, to facilitate random mating. Methods for effective recurrent selection will be tested, and linkages with efficient variety development procedures developed.

Increasing yield potential

Increasing yield potential is the underlying target of this research, for a wide range of production conditions, including those with higher input availability. Experience of the past 30+ years by barley, pearl millet and sorghum breeding programs has been that this requires most effective integration of selection for key adaptation traits, as well as capacity for effective testing of yielding ability. Experience shows that it is essential:

- To conduct disease resistance selection in whole segregating populations and not only among advanced lines. Breeding populations should be planted in hotspot areas, preferably where natural conditions make escapes minimal, and inoculation-misting irrigation may be used in case the natural conditions are not enough to generate optimum levels of diseases.
- To perform at least two generations per year under full selection.
- To be based in a country where the majority of economically important diseases for the target environment can be addressed, where yield trials can be carried out under target input conditions, and where quarantine barriers do not block or delay germplasm movement across borders.

Marker assisted breeding and population improvement.

Use of molecular markers contributes to efficiency in breeding, in a variety of crops and target regions. Among the dryland cereals these tools are best developed for barley, mostly targeting industrialized farming conditions. Similarly for sorghum rapid advances are being documented (Jordan et al., 2011). It is essential that these tools and opportunities be exploited for and with dryland cereals breeding programs targeting the farming conditions described in this CRP. Based on results and outputs from Strategic Objective 2, the full-scale application of these tools will be developed for key crops, NARS and other partners, as well key traits for priority production systems (Tables 6 and 7)

The improvement of the popular Indian hybrid 'HHB 67' by introgressing new genes for downy mildew resistance is one of the first examples of creating a commercial cultivar using genetic markers (Hash et al., 2006). We expect that marker assisted backcrossing will start to become a routine for dryland cereal breeders, especially once farmers' needs and preferences are better understood, and will evolve. We are starting to experiment with using markers to support population improvement, with a rather broad based pearl millet population, and a bi-parental population in sorghum. Application of marker and direct sequencing approaches that are or will become extremely useful in the near future for increasing the efficiency of multiple trait focused breeding methods, as well as for correcting or improving very specific characteristics of farmer preferred cultivars, e.g. "HHB 67 improved".

Breeding and improving hybrids and hybrid parents

For sorghum and pearl millet, hybrids are commonly used in commercial agriculture. The breeding programs for sorghum and millet focus primarily on breeding female parents, while the private sector does develop their own male parents. In SSA, the first locally bred sorghum hybrids were released in 2009 in Mali (Diallo et al., 2009), and are starting to attract the attention of producers, extension agents and private local seed producers.

Demand by large industrial grain processers (malt, starch) in Nigeria for hybrids is high to assure more dependable supply of uniform product. Sorghum hybrids in Mali show average yield superiorities of 20% on-farm are achievable; need for different hybrids for specific rainfall/maturity zones and attention to grain quality/mold resistance necessary. Actions: develop first hybrids with adaptive- and grain quality-traits appropriate for Nigeria; develop hybrids for distinct maturity zones; and MET yield testing.

Diversifying male-sterility inducing cytoplasm

The success of hybrid breeding in dryland cereals depends on reliable genic cytoplasmic male-sterility systems for hybrid seed production. For both, sorghum and pearl millet several such cytoplasms have been identified – and could be used. We will be exploring options for diversifying the cytoplasms use by the private sector in India, to reduce potential vulnerability.

Milestones

- At least ten superior hybrid parents for diversification of for hybrid breeding options for sorghum and pearl millet in SA and starting hybrid breeding in WCA identified (2012)
- At least two new finger millet, sorghum and barley varieties identified for promotion in at least two target production systems (2012)
- Pearl Millet and Sorghum populations initiated for recurrent selection for adaptation to at least two specific new target conditions (2013)
- Analysis of genetic diversity patterns of prior studies combined with new studies for improved identification of heterotic groups for breeding hybrid parents of sorghum and pearl millet (2013)
- Methods tested for improving efficiency of crossing in finger millet (2013)
- Superior sorghum parents for total biomass yield and specific quality trait identified (2014)
- Populations of barley developed with increased out-crossing rate using recurrent selection, and morphological as well as biochemical markers (2014)
- Efficiency of recurrent selection schemes for sorghum and pearl millet for target production systems with high variability and poor predictability of abiotic constraints assessed (2014)
- At least 200 genetically diverse, high-yielding and locally well adapted early-generation restorer progenies of A4 and A5 CMS systems developed in pearl millet and female and male parents for A1, A2 and A4 CMS systems for sorghum for at least two target production systems (2014)

Output 3.2. Varieties and hybrids with better tolerance to heat, drought, salinity and low soil fertility

Adaptation to drought and heat during key growth stages

Dryland cereals, by definition, are well adapted to drought and heat stress during key stages of crop development, and can produce grain and straw/stover when other crops fail. However improved adaptation to drought and heat conditions is necessary for improved yield stability over years, to reduce the negative effects of increasing unpredictability of rainfall and water availability on food security and income of dryland farmers, in view of climate change. Field evaluation protocols for drought tolerance during specific growth stages in specific target environments (Bidinger et al., 1987), Reddy et al. 2009,) have been developed for all cereals except finger millet, and will continue to be refined and adapted to ensure that new breeding materials perform consistently well in their target environment. The concept of plant ideotypes will continue to be applied, in conjunction with crop modeling research (in collaboration with Strategic Objective 1 and Strategic Objective 2) to identify new selection criteria (Van Oosterom et al., 2006) and trait combinations to enhance drought tolerance of highly productive genotypes. The pleiotropic effects of specific traits associated with drought tolerance, e.g. 'stay green' will be evaluated for their effects on grain yield and total plant value under diverse growing conditions. As genetic marker tools become more accessible to breeders, a range of agronomic traits will be used to support variety development programs, including root traits (Grando and Ceccarelli, 1995). Close interaction with Strategic Objective 2 will enable breeders to improve the rate of genetic gain for these complex traits. A broad range of germplasm, including wild relatives will be explored to identify sources of tolerance that can effectively increase drought tolerance of target genotypes (Baum et al., 2003; Lakew et al., 2010;

von Korff et al., 2010; Varshney et al., 2008a; 2008b; Eleuch et al., 2008; Jilal et al. 2008; Guo et al. 2008, 2009).

Low soil phosphorus availability, low pH and potential Aluminum toxicity

As world phosphorus reserves are rapidly declining, and dryland cereal farmers even now can rarely afford to purchase fertilizers, we are exploring the diversity within dryland cereal species for adaptation to low P availability. In addition to field trials under low soil P conditions, we are including root traits to the characterization data, which will be used for an association study to identify genes associated with phosphorus efficiency, building on recent advances in rice (Wissuwa et al., 1998, 2002; Heuer et al., 2009). Simultaneously we are developing breeding populations including known source materials with good adaptation to low soil P availability and with known Al-tolerance (Magalhaes et al., 2007), adapted to specific target zones across SSA. We expect useful learning experiences across crops for breeding for root, and soil adaptation traits.

Improved understanding of the control of flowering responses of dryland cereals

Experienced dryland cereal breeders estimate that 80% of the variability for yield under drought conditions tends to be due to differences in flowering response. 'Flowering date' tends to be regarded as a simply inherited trait, and single genes governing some aspects of it, especially earliness, are known for most dryland cereals (Von Korff et al., 2010, Wang et al., 2009). We will be improving our capacity to use specific photoperiod responses to achieve more predictable flowering in specific target zones, e.g., post-rainy season sorghum, winter barleys, or sorghum for the Sudan savannah of West Africa (Clerget, 2004, Clerget et al., 2008). Evaluation protocols, including methods for recording farmers' assessments are being adapted to the specific requirements. We have initiated studies to improve insights into interaction with other abiotic stress, temperature, high and low and phosphorus availability in the soil. This improved understanding of flowering responses will help to better delineate expected adaptation domains for specific varieties.

Temperature extremes

Pearl millet and sorghum, to some extent, have extraordinary adaptation to heat, during the seedling stage up to 60+ C^{o} (Peacock et al., 1987); during flowering up to 42 C^{o} (C.T. Hash, pers. Comm.), As global warming is predicted to lead to significant temperatures increases in the dryland cereal and maize growing areas of SSA interest in this trait is increasing. We have started to develop field-screening procedures for some of the cereals, and will characterize more of the diversity available in current breeding materials. We plan to expand this work to include a wider range of germplasm, before deciding about the feasibility of genetic studies on this trait.

Cold tolerance, during key growth stages is an issue being addressed for dryland cereal cultivation during the cool season. For barley there are good prospects of strengthening the breeding for cold areas in collaboration with NARS of Central Asia and Iran. For post rainy season sorghum a screening protocol is being refined and germplasm from other cool-season sorghums will be evaluated, for possible use in variety development programs.

Salt tolerance

Sorghum area of late is being extended to saline soils for fodder purpose. Hence in collaboration with NARS, materials developed for rainy season and post rainy season adaptations will be screened for tolerance to salinity following the methods described by Krishnamurthy et al. (2007).

Barley is the most salt-tolerant of the cereal crops. The development of salt tolerant varieties remains the only sustainable solution for reliable yield advantages. To respond to increased request from NARS, research on salinity tolerance will be initiated in collaboration with NARS and ARIs. ICARDA has established a high throughput screening facility for salt tolerance in seedling stage that can also be used for other crops. Procedures for evaluating salt tolerance for other crops at ICRISAT will be tested.

Methodology

Coordination across species

Research in several crops indicates some clear commonalities in how crops species adapt to common abiotic stresses. For example pearl millet and chickpea, both facing terminal water stress, adapt thanks to water saving mechanisms (Kholova et al., 2010a, 2010b; Zaman et al., 2011a, 2011b). Similarly, salinity appears to affect mostly reproduction in groundnut (Srivastava et al., under review) and chickpea (Vadez et al., 2007, Krishnamurthy et al., 2011). So, there are common aspects in the crop adaptation to stress across species and the most efficient and synergistic way to tackle it is to have an initial coordination effort of the protocols and approaches that are used to assess plant performance. The intention here is to have a broad spectrum of expertise, going beyond the CGIAR system, being brought in to refine research on this topic. This will include collating experiences with specific field screening procedures and whole plant observations and sites. We expect to create communities of practice around specific abiotic stress factors.

Allele mining for flowering response

Merging of high-density genotyping-by-sequencing haplotype data with previously generated multi-environment flowering time response data from > 40 managed and natural photoperiod-temperature environments for a panel of 120 sorghum landraces from the full range of production environments globally will permit detection of allelic variants in essentially all major genes contributing to photoperiod-temperature response of flowering in this species. These allelic variants will then be used to breed for appropriate flowering response in a range of climate change scenarios, reducing the likelihood of exposure to terminal drought stress. We expect that with this information we shall be better able to understand interactions between grain and stover yield potential of photoperiod sensitive sorghums (Clerget, 2004). This may prove useful for pearl millet improvement as well.

Interdisciplinary efforts for nutrient efficiency

Improvements of the field phenotyping capacity for adaptation to low phosphorous availability and *Al*-toxicity, developed by IER, INRAN and ICRISAT in Mali and Niger will continues with support from soil scientists. These experiences will inform other crop teams. We will add capacity for root trait analyses, starting with field-based observations, following the model developed for maize and soybean. Should they not yield the expected results, we will explore 2D, or possibly 3D imaging tools for roots grown in vitro in standardized media (Kupper and Kochian, 2009). With a diversity of phenotypic observations on a panel of 120 sorghum varieties, we plan to conduct association studies for the identification of useful alleles, for use in breeding.

Verification of concepts, tools and traits in multi-location trials

The extensive experiences of all partners in this CRP with field performance evaluation under target production conditions for dryland cereals, including some of the harshest climates for crop production is a unique opportunity for “ground truthing” new developments, traits, combinations and populations. Experiences with such long-term trials show that they also provide new insights, and give rise to testing hypotheses about adaptations to extremes of specific abiotic stress, and their importance to farmers (Weltzien and Fischbeck, 1990; Bidinger et al., 1994; van Oosterom et al., 2006; Reddy et al., 2009; Ceccarelli et al., 2010). Similarly such experimentation can lead to the identification of new varieties for release and dissemination, especially if farmers get involved in the evaluations. Using the large germplasm collections held by the CRP partners has been instrumental to these successes.

Application of marker based tools for breeding

Barley is one of the few crops with well-documented genomic tools available. These experiences will guide work on the other crops, in collaboration with Strategic Objective 2. QTLs associated with abiotic and biotic stresses will be assembled and favorable alleles pyramided using MAS. Where applicable, MAB would be employed to fast track defect elimination in elite germplasm, preferred by farmers. Similarly, information from historical datasets from the barley breeding program especially the germplasm that have been characterized with markers would be utilized in targeted genome wide selection to accumulate small effect QTLs associated with complexly inherited traits conferring tolerance to drought and heat. 'Ground- truthing' will be done using existing field screening facilities, such as the off-season screening facility for pearl millet and sorghum, developed at ICRISAT in India (Bidinger et al., 1987)

Milestones

- QTLs identified for traits related to drought tolerance for at least two species (2012)
- Analyses of genotype by environment interactions of variety performance trials of dryland cereals linked to water availability estimates for specific production systems and zones for at least two dryland cereals (2012)
- Protocol for drought tolerance screening developed for finger millet in ESA (2012)
- At least 10 parental lines of pearl millet, sorghum, finger millet and barley adapted to arid conditions developed (2013)
- Core set of genetic stocks representing effective sources of drought, heat-adaptation and salinity tolerance traits assembled in barley, pearl millet and sorghum (2013)
- Stability of at least one specific drought tolerance trait assessed in a range of target genotypes in naturally drought-prone environments, for at least two species (2014)
- Markers identified for genomic regions conferring P efficiency in sorghum (2014)
- Salinity tolerant varieties of sorghum and barley (3) and hybrids of sorghum (2) with high biomass and grain yield in at least two target production systems developed (2014)

Output 3.3. Varieties and hybrids with improved resistance to diseases and pests

Biotic stresses of dryland cereals are as diverse as the crops and their production systems. Insect pests and diseases of dryland cereals have very specific and evolving distribution patterns, which are likely to change with climate change and the intensification of certain production systems. They cause an estimated loss of over US$ 2.5 billion annually, excluding barley and finger millet (Sharma, 2006). Varietal resistance is the most important option for reducing losses due to biotic constraints, often supported by crop management measures to arrive at more sustainable IPM options (Strategic Objective 4).

Tolerance to insect pests and to the parasitic weed *Striga* tends to be more complex and requires improved understanding of the parasite's biology, population dynamics and epidemiology to improve chances of finding durable levels of resistance or tolerance, as well as developing integrated management options for sustainable crop production (Strategic Objective 4). The key to their sustainable genetic management will lie in the monitoring of spatial and temporal variability in the pathogens, and identification of new resistance sources.

Screening protocols for many diseases and insect pests of dryland cereals have been developed over the past 30 years, and used successfully to identify sources of resistances, as well as for breeding resistant varieties for dissemination (Sharma, 2006; Haussmann et al., 2000). However, refinement of these tools will be required to improve efficiency, and adapt to the changes in pathogenicity of the specific pests. Field and controlled environment screening procedure will increasingly be managed by individual NARS, accounting better for pathogen diversity.

Achieving durable disease resistance remains a key challenge. We will increase emphasis on the use of non-race specific resistance. In barley for example, there are reports (Chen at al., 2010) on the identification of QTLs for non-race specific resistance in fungal diseases such as stripe rust and leaf blotch. Integrating marker-assisted (MAS) selection with conventional breeding approaches will enhance the capacity to develop dryland cereal germplasm with enhanced levels of durable disease resistance. As new loci/genes for disease resistance are mapped, it will be possible to pyramid these resistance alleles by MAS. Pyramiding of multiple resistance genes through MAS may result in more durable or higher levels of resistance. Similarly MAS shall improve our capacity to produce lines with resistance to multiple diseases and pests.

Methodology

Identification of new sources of resistance, and refining screening protocols

New sources of resistance are required for fungal diseases, as well as *Striga*, because of high levels of genetic diversity, or adaptability to the host plant's spectrum of resistance genes, e.g., in downy mildew in pearl millet (Thakur and Sharma 2009; Singh et al., 1993), blast in finger millet, and lately also on pearl millet in SA, anthracnose in sorghum, and rusts in barley. While screening protocols for these diseases exist, they require refinement, detailed analysis and documentation, and adaptation to the specific conditions of specific regions and production systems. We will focus efforts on the following host-pathogen systems:

- Field screening for *Striga* resistance in pearl millet needs to be documented for WCA;
- Downy mildew screening facilities for pearl millet need to be established in WCA;
- Sorghum and barley aphid resistance protocols need to be refined (SA, CWANA);
- Develop *Striga* screening facility for Finger Millet in ESA;
- Blast on pearl millet in SA;
- Blast on Finger millet in ESA;
- Charcoal rot in post rainy season sorghum in SA;
- Foliar diseases (scald, Net botch) for barley;
- Barley Yellow dwarf virus in relation to drought in barley;
- Wheat stem saw fly and barley gall midge in barley for CWANA; and
- Rusts on barley for SA and ESA

Monitoring the pathogen diversity and improved understanding of resistance mechanisms

Understanding of underlying mechanisms of resistance is required to identify diverse sources of resistance for gene pyramiding, and develop high yielding cultivars with adaptation to different agro-eco-systems. While host plant resistance is an effective tool to manage certain pests (e.g. midge in sorghum and downy mildew in pearl millet, foliar diseases in sorghum and finger millet and barley), there is need to develop other tools of IPM for managing other pests, please see Strategic Objective 4. Improving the understanding of the diversity patterns of priority fungi, insect pests, and Striga will help targeted deployment of known sources of resistance.

As we have observed in the past, that the pressure of a specific pest may not be evident, when basing diagnostics solely on local landrace varieties. In cases where "exotic" sorghum, pearl millet or barley materials were introduced into an area, they were devastated by insects which had not even been identified as pests before, e.g., head bugs on caudatum race sorghum in the Sudanian zone of West Africa. Thus breeding experiments will require regular monitoring by entomologists to avoid increasing production risks to farmers. We therefore will focus our efforts on the following:

- Sorghum midge resistance screening results need be globally compared, to identify regional differences;
- Stability of resistance to stem borers across different species between ESA and SA;
- Shoot fly and aphid resistance in post-rainy season sorghum in SA;
- Identification of genetic differentiation of *Striga* strains in relation to their virulence in WCA;
- Blast of pearl millet in SA;

- Blast of finger millet in ESA;
- Virulence analysis of populations of foliar diseases of barley in CWANA;
- Interaction of BYDV and drought in barley in CWANA; and
- Biotype variation of Russian Wheat Aphid on barley in CWANA.

Tools to transfer new resistance genes into farmer preferred varieties

The effectiveness of transferring newly identified resistance sources into elite breeding materials is a key element for demand responsive breeding programs. We plan to improve tools for marker assisted transfer of specific resistance QTLs into target materials, as well as improve tools for identifying progenies from bi-parental crosses as well as broad-based breeding populations with resistance or tolerance to specific pests.

- Marker assisted transfer of *Striga* resistance QTLs into farmer preferred sorghum varieties
- Marker assisted transfer of shoot fly resistance in to farmer preferred cultivars
- Phenotyping procedures and RILs for aphid resistance in sorghum in SA
- Identification of QTLs for *Striga* resistance in pearl millet
- We plan to conduct research on the feasibility of transferring the *Striga* control options based on a herbicide tolerant crop from maize to sorghum and possibly pearl millet

Milestones

- Sources of resistance to fungal leaf and root diseases identified in both cultivated and wild barley (*H*. *vulgare* subsp. *Spontaneum* and *H*. *bulbosum*), including parents of existing mapping populations, as well as for finger millet (blast and Striga) assembled and multiplied (2012)
- Screening protocols refined to identify sources of resistance or tolerance to specific pests and diseases (head miner in pearl millet; midge on sorghum, aphids on sorghum and barley), diseases (blast in pearl millet and finger millet; grain molds in sorghum, net blotch, mildew, scald, and BYDV and Wheat stem sawfly and barley gall midge in barley in CWANA, rust in SA and ESA (2012)
- Elite composites of pearl millet with combined resistance to downy mildew and blast developed (2012)
- Hybrid parental lines or varieties with resistance to downy mildew in pearl millet (WCA, SA), blast in pearl (SA) and finger millet (ESA, SA); *Striga* on sorghum in WCA, foliar diseases and grain mold in sorghum and barley; and shoot fly, stem borer, and aphid in sorghum, and aphid in barley identified and distributed to NARS (2013)
- Off-season downy mildew screening facilities for pearl millet installed in at least one country in WCA (2013)
- Genetic diversity of *Striga hermonthica* samples from WCA assessed using molecular markers (2013)
- Evolution of virulent strains of downy mildew in pearl millet, blast in finger and pearl millet, and net blotch, powdery mildew, scald and rust in barley monitored, and the information shared with NARS (2014)
- Marker assisted transfer of specific resistance/tolerance alleles into farmer preferred varieties documented (Downy mildew on pearl millet, *Striga* and shot fly on sorghum, foliar diseases for barley) (2014)
- QTLs or allele markers identified for the transfer of specific resistances/tolerances into target genotypes (*Striga* on pearl millet, aphids on sorghum, foliar diseases of barley) (2014)

Output 3.4. Varieties and hybrids with enhanced green forage, stover and straw varieties for fodder and other uses

The increasing demand for livestock products along with decreasing availability of arable land and water will not only increase the demand for green forage but especially for dry stover/straw, that is crop residues after grain harvest, to feed livestock. We will bring about a paradigm shift in dryland-cereal variety development to breed concomitantly for superior grain and green forage/stover/straw traits, to maximize total plant value for dryland cereal farmers. Given the substantial and largely untapped genetic variability present for feed/fodder quality traits in all species included in this CRP, and the ready availability of high-throughput, breeder-friendly selection technologies (NIRS), significant genetic progress for fodder quality and the development of successful dual-purpose cultivars adapted to dryland farming systems are likely to occur rapidly. Marker-assisted selection (MAS) will be used to increase the efficiency of selection for green forage/stover/straw quality traits (Grando et al., 2005).

This research component will create new varieties with enhanced quality and greater total value that possess new trait combinations by building on currently available genetic variability for food and feed in the major dryland cereals.

Methodology

Exploit existing varietal diversity for food-feed traits in dryland cereals

Expanding our shared knowledge of straw and stover fodder traits in existing varieties, breeding lines, including sweet stem sorghums and populations is needed. Promising sets of farmer identified varieties and materials from national and international breeding programs will be evaluated for stover/straw/fodder quality and agronomic traits. Evaluations of materials from gene banks and core collections would be pursued where necessary to and expand the diversity for targeted traits.

Drawing on preliminary work by CIMMYT, ICARDA, ICRISAT and ILRI, we will use Near Infrared Spectroscopy (NIRS) to characterize lines for a range of traits targeting improved intake and digestibility (Bluemmel et al., 2009). The centers' with compatible NIRS laboratories will exchange NIRS equations to ensure that progress can be made in all target regions. We will improve and adapt evaluation methodology and identify sets of varieties with superior stover/straw quality, as a basis for identifying lines and varieties with optimized total plant value. Varieties will be identified for dissemination, characterization and quantification of any trade-offs between straw and stover fodder traits with grain traits.

Develop true multipurpose dryland cereals that optimize grain and fodder production under farmers' growing conditions

In specific cases, post-rainy season sorghum in SA, barley for the dryland mixed systems in CWANA, and sorghum for the Cereal Root Crop Mixed systems of WCA, we will pursue targeting breeding of new dual or multipurpose types by exploiting the genetic diversity and integrating the new traits into ongoing recurrent selection and variety development programs, assisted by genetic markers. This we will create novel plant types, improved populations and varieties with superior quality or quality and agronomic trait combinations that surpass previously available materials. Targeted breeding for high fodder/stover/straw quality will require breeding for resistance to foliar diseases, e.g. blast and rust for pearl millet, anthracnose and specific leaf spots for sorghum, which have shown to significantly reduce fodder quality. Comparisons of effectiveness of alternative breeding methods will be part of the program.

We will conduct farmer participatory breeding and varietal evaluations of new materials in the context of their production objectives, physical environments and resource constraints. This will create opportunities to jump-start adoption and linkage with value chain enhancement identified (Strategic Objective 6).

Milestones

- Review of options for improving total plant value of dryland cereals conducted by CRP partners, across crops and production systems (2012)
- Experimental varieties of sorghum, pearl millet and barley characterized for components of total plant value for specific production system scenarios (2012)
- NIRS protocols transferred to all target regions, and available for breeding programs for analyzing straw/stover quality components (2013)
- Sweet sorghum germplasm accessions (3) for multicut trait identified in SA from the global collection (2013)
- High biomass sweet sorghum lines (3) introgressed (to BC2) with low lignin *bmr* genes (2014)
- Dual purpose varieties identified for at least 2 dryland cereals in different target production systems combining superior grain yield with increased straw/stover value (2014)
- Marker assisted selection successfully applied to increase quality and value combined of stover and grain beyond released cultivars for at least one dryland cereal (2014)

Output 3.5. Varieties and hybrids with enhanced grain qualities for food, feed and industrial uses

Grain quality includes those traits that are apparently visible in the grains (size, shape, color, texture, storability) and are of direct immediate value to farmers and consumers. These will continue to remain integral part of genetic enhancement of all the dryland cereals. However, many quality traits of considerable nutritional and industrial significance are invisible. Considering the widespread iron and Zn deficiency (FAO, 2002) and its serious health consequences, genetic enhancement of the concentration of these two micronutrients will have the highest priority. This area of research has reached the stage of breeding and it is gradually being integrated with the mainstream breeding in pearl millet targeted to India, which is included in subcomponent 1 of component 2 of the CRP 4. In other dryland cereals, the research will be confined in the medium terms to identify and validate sources of high iron and zinc content among advanced breeding lines and cultivars, and to undertake strategic research to investigate their inheritance, stability and character associations. The commercial and pipeline cultivars will also be evaluated to assess the extent of variability for other traits affecting nutrition and health (e.g. protein, fat, phytates, bioactive compounds) and industrial and pharmaceutical values (starch).

For barley, and increasingly sorghum malting quality is an important industrial trait, increasing requested by NARS, and other stakeholders. Selection for malting quality requires expensive infrastructure, therefore the program will establish linkages with the private sector and ARIs to develop high malting quality barley germplasm, from which sorghum may also benefit.

About 75% of production of barley, and increasingly sorghum and pearl millet (Parthasarathy Rao et al. 2010) is utilized for animal feed, in the target production systems of this CRP due to very high levels of small ruminant animals in these production systems. The global shortage of feed grains and concomitant increase in price combined with threats from climate change make improvements in feed quality in addition to productivity and stability (Output 1) the dominant breeding objectives.

Methodology

Near Infrared Spectroscopy (NIRS) has been used effectively for screening for Fe and Zn content. Recently an XRF method has been tested for pearl millet under the HarvestPlus Challenge Program (now included as a sub-component in CRP 4) and found even more effective than NIRS. Its correlation with ICP values both for Fe and Zn is generally very high ($r > 0.85$), it is non-destructive analysis, can handle 250-300 samples a day and costs < US$ 1/day. Its standardization for other dryland cereals can greatly enhance the breeding efficiency for these minerals.

Grain hardness (Bean et. al., 2006) and diameter measurement shall be an important quality parameter to be monitored for establishing suitability for milling of grains to produce high quality flour. Functional properties (Vijayakumar and Mohankumar, 2009) such as diastatic activity, germinating power, water solubility index, water absorption index, water holding capacity, oil absorption capacity, thermal and pasting properties (using Rapid Visco-analyser-RVA) shall be used for characterization of the grains for various processing applications. In vitro digestibility (protein, starch) of the grains shall also be looked into using standard methods of analysis in order to explore their use in both the food and feed processing industry. Nutritional profiling along with profiling for key amino acids (Ejeta et. al., 1987) shall be carried out as part of profiling the grains for use in the food and feed industry. In addition measurement of starch for identifying suitable candidates for extraction of starch to be used in various industrial applications covering the pharmaceutical, paper, food, petroleum etc. industries shall be carried out. Rapid methods (Mccleary et. al., 1994) for measurement of starch using enzyme assay kits are available for this purpose.

Profiling of bioactive compounds such as phenols, condensed tannins, flavan-4-ols and anthocyanins shall be carried out. The phenolic compounds present in grains are phenolic acids, flavonoids, and condensed tannins. The following phenolic acids shall be quantified, using standard HPLC methods (Hahn et al., 1983); gallic acid, Protocatechuic, p-Hydroxybenzoic, Vanillic, Caffeic, p-Coumaric, Ferulic and Cinnamic acid. The major class of flavonoids in dryland cereals is the anthocyanins. Anthocyanins in sorghum are unique since they do not contain the hydroxyl group in the 3-position of the C-ring and thus are called 3-deoxyanthocyanins. This unique feature increases their stability at high pH compared to the common anthocyanins that confer to these compounds the potential to serve as natural food colorants. In addition, these compounds have antioxidant activity. Other flavonoids reported are Flavan-4-ols (Luteoforol, Apiforol), Flavones (Apigenin, Luteolin), Flavanones (Eriodictyol, Eriodictyol 5-glucoside, Naringenin), Flavonols (Kaempferol 3-rutinoside-7-glucuronide), Dihydroflavonols (Taxifolin, Taxifolin 7-glucoside). Condensed tannins are measured using the vanillin/HCl or the butanol/HCl assays. In vitro antioxidant activity shall be measured using the 2,2'-azinobis(3-ethyl-benzothiazoline-6-sulfonic acid (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and oxygen radical absorbance capacity (ORAC) methods (Awika et. al., 2003).

The poultry feed is supplemented with methionine to increase the efficiency of poultry diets, and millets being rich source of methionine with balanced amino acid profile have shown better results than maize when used as broiler diet. The methods are available to study amino acid profiling, especially methionine content; oil, fiber and protein content which are important components of poultry diets and if improved can significantly enhance the quality and production potential of poultry-based products. This will apply to barley as well.

Milestones

- Rapid and cost-effective screening protocols for mineral analysis in grain (Fe, Zn and Ca) of sorghum and millets standardized (2012)
- Finger millet grain profiled for key nutrients and minerals, based on a range of cultivars and advanced breeding lines from ESA and SA (2012)
- Decortication losses of a range of sorghum and pearl millet cultivars quantified, also for the consequences for Fe and Zn concentration, and indications for their bioavailability (2013).
- Source materials with high mineral content identified among advanced breeding lines, and commercial/pipeline hybrids/varieties of sorghum (pearl millet in CRP 4) (2013)
- Commercial and pipeline cultivars of pearl millet and barley characterized (at least 40 in each crop) for poultry and small ruminant feed quality traits, including anti-nutritional factors (2013)
- Screening protocols for screening barley germplasm for malting quality (2013)
- Commercial and pipeline cultivars (at least 40 in each crop) characterized for processing and value-addition related nutritional traits, and starch and bio -active compounds (2014)

Partners and Their Roles

Direct collaboration between researchers from a wide range of disciplines from different partner institutes for solving a priority problem will be essential to implementing Strategic Objective 3. The key to engaging partners will be to focus on the common goal of enhancing cereal farmers' livelihoods and to put mechanisms in place to ensure that activities are needs based and demand driven. Research partnerships with universities and advanced research institutes for specific technical, social and institutional issues are needed as well. Regional cooperation within the same agro-ecological zones, involving the exchange of germplasm, concomitant diversification of national breeding materials (to increase heterozygosity and therefore hybrid vigor in the hybrids), and joint multi-location hybrid evaluation trials within similar agro-ecological zones (across countries) will enhance hybrid breeding efficiency in SSA.

- GCP/CIRAD will contribute to output 3.1: by development of new sorghum varieties from "good x good crosses" representing new allelic combinations of QTLs for productivity, adaptation, and grain quality (GCP: MARS project); and by development of sorghum varieties from elite backgrounds incorporating favorable alleles for adaptation, productivity, and grain quality (GCP: BCNAM project);
- ICRISAT will contribute to output 3.1: through its sorghum and pearl millet variety development expertise and facilities for multi-location testing all priority production systems listed in ESA, WCA and SA, as well screening and monitoring of locally important pests and diseases important for adaptation; and through its finger millet breeding expertise and facilities in ESA;
- ICRISAT will contribute to output 3.2: through its off-season drought nursery for pearl millet and sorghum in SA; its rainout shelter with lysimeter-based screening facility for water use efficiency, and other physiological observations for drought, heat and salinity tolerance evaluations in SA (and now being established in WCA); and through low phosphorus field testing facilities for sorghum and pearl millet in WCA and Al-tolerance field testing facilities being established for sorghum an pearl millet in WCA;
- ICRISAT will contribute to output 3.3: by providing controlled environment, as well as field screening facilities for pearl millet downy mildew in SA (which is now being established in WCA, as well); via use of its sorghum entomology and grain mold screening facilities in SA; through its *Striga* screening facilities in WCA; through its capacity for monitoring midge infestations and foliar and grain diseases on sorghum in WCA; and through its blast screening facilities for finger millet in ESA;
- ICRISAT will contribute to output 3.4: by conducting laboratory analyses for Fe and Zn (atomic absorption spectroscopy and XRF) in SA, through its capacity for assessing decortication losses and culinary qualities of sorghum and pearl millet in WCA, and via the Nutriplus food processing business incubator facilities in SA;
- ICRISAT will contribute to output 3.5: by conducting biomass assessments in all regions on sorghum, pearl millet and finger millet; through its stover milling capacity in SA and WCA; and through its capacity for sweet sorghum characterization (sugar yield) in SA and WCA;
- ICARDA will contribute to output 3.1 by breeding for high potential areas (spring types) – with a focus on the development of germplasm for favorable environments with a strong focus on yield potential and biotic stresses in areas with more favorable levels of inputs. This component will also coordinate the work on malting barley. Target countries will include South and East Asia, Latin America, as well as the more favorable areas in other regions.
- ICARDA will contribute to output 3.2 by breed for low potential areas (spring types) – with a focus on adaptation to abiotic stress such as drought, cold, heat, and salinity, and associated biotic stresses. Target countries are West Asia, East and North Africa, Central Asia (spring types), as well as less favorable areas in other regions. Screening facilities at ICARDA

headquarters will be used for identifying salt tolerance in the seedling stage. Breeding for winter barley will be done both for high and low potential areas – with a focus on winter hardiness and other associated abiotic and biotic stresses. Target countries are Iran, Central Asia and the Caucasus, as well as winter growing areas in other regions.

- ICARDA will contribute to output 3.3 by testing segregating populations and fixed lines in hot spots for different diseases and pests. Sources of resistance will be characterized at headquarters and transferred into the breeding material with the help of conventional and marker-assisted selection. Controlled environment facilities, a biosafety facility as well as field-testing facilities are available at ICARDA headquarters.
- ICARDA will contribute to output 3.4 though its cereal quality laboratory, which will conduct tests for micronutrient (mainly Fe and Zn), beta-glucan, and protein content, in addition to standard assessments of physical grain quality using NIRS;
- ICARDA will contribute to output 3.5 by conducting cereal grain quality analyses for traits related to malting quality at the ICARDA laboratory, in collaboration with ARIs;
- ILRI will contribute to output 3.4 by: advancing methodology development for using NIRS to predict relevant fodder and feed quality parameters for use by dryland cereal breeding programs in SA, WCA and ESA; and by conducting research on options for fodder densification and marketing, focusing on SA, but expanding to WCA, for sorghum.
- CIRAD will contribute to output 3.1 by: development and intensive evaluation of photoperiod-sensitive sorghum and pearl millet varieties with reduced plant height, improved harvest index and adequate grain quality for Mali (FFEM-2 project); and to output 3.5 by developing: improved food-feed-fuel and feed-fuel sorghum germplasm for semi-arid conditions and acid soils (SweetFuel project);
- INTSORMIL will contribute to output 3.1 by contributing methodological experiences on pearl millet and sorghum variety development; to output 3.2 by providing sorghum germplasm identified for specific abiotic stress tolerance components for use in ESA and WCA; to output 3.3 by providing sorghum and pearl millet germplasm with identified components of *Striga* resistance for use in ESA and WCA, by contributing to improvements in screening methodologies for key sorghum insect pests in WCA and ESA, and by contributing identified sources of anthracnose resistance, and new tools for disease screening; to output 3.4 by providing expertise in cereal processing technologies and analytical methods, and via its experience with managing cereal processing business incubators; and to output 3.5 through their experience with forage use and forage variety development, primarily of pearl millet. Overall, INTSORMIL will contribute by providing advanced/degree training opportunities for African students and scientists.
- Kansas State University, Department of Grain Science and Technology (USA), will contribute to output 3.5 by validating results on nutritional and functional properties of pearl millet grains, especially with regard to utilization of the grains for industrial processing, and through the development of value-added products from pearl millet grain;
- University of Hohenheim (Germany) will be contributing to output 3.1 by supporting research on heterotic grouping in both sorghum and pearl millet with a focus on WCA; to output 3.2 by contributing to research methodology development for breeding for adaptation to low P conditions in WCA, the identification of markers for photoperiod sensitivity in sorghum and pearl millet in WCA, and breeding methodologies for finger millet in ESA; and to output 3.3 by conducting ecological studies on *Striga* distribution in West-Africa;
- University of Wageningen, Department of Nutrition (Netherlands), will contribute to output 3.5 by facilitating the coordination of the INSTAPA project, and thus bioavailability studies of sorghum and pearl millet grains and processed food products, as well as efficacy studies, using als biofortified sorghum and pearl millet varieties;

- University of Pretoria, Department of Food Science (South Africa) will contribute to output 3.5 by validating of the results involving nutritional, functional and bioactive analysis of the grains;
- Alberta Agriculture, Food and Rural Development (AAFRD-Canada) will contribute mainly to 3.1, 3.3, 3.4 and 3.5 by evaluating and selection of barley germplasm for disease resistance and agronomic performance; they offer excellent NIRS analysis capacity as well, which will contribute to feed, food and malting quality testing;
- Oregon State University (USA) will contribute to 3.1 and 3.3 through molecular mapping of barley within the North America Barley Genome Mapping project and identification of molecular markers associated with resistance to diseases of barley;
- The Scottish Crop Research Institute (SCRI): will contribute to 3.1 and 3.2 through genetic analysis of drought tolerance and adaptation in barley;
- University of Adelaide, Waite Institute (Australia) will contribute to 3.1, 3.2, and 3.5 through joint evaluation of barley germplasm for low rainfall environments, and for salt stressed environments;
- University of Sydney Plant Breeding Institute (Australia) will contribute to outputs 3.1 and 3.3 through evaluation of barley germplasm for resistance to barley stripe (yellow) rust at the Cobbitty-based cereal rust research facilities;
- University of Bedfordshire (UK) will contribute to output 3.3 by working on the genetics of the blast pathogen, and the resistance to it in finger millet;
- University of Georgia, Athens (USA) will contribute to output 3.3 by working on the genetics of the blast pathogen and resistance to it in finger millet and pearl millet;
- EMBRAPA's Sorghum and Maize program will contribute to output 3.2 by providing support and training for Al-tolerance and testing for low P adaptation, as well as marker applications;
- The All India Coordinated Pearl millet Improvement project will contribute to outputs 3.1, 3.2, and 3.3 by conducting field trials to generate yield, and biotic/abiotic resistance/tolerance data, and by contributing to in scientific capacity building and impact assessment as well as organizing annual consultation meetings among pearl millet stakeholders, and by coordinating variety release procedures for India;
- The Directorate of Sorghum Research (DSR), Hyderabad, India, will contribute to outputs 3.1, 3.2, and 3.3 by conducting field trials to generate yield, and biotic/abiotic resistance/tolerance data, and by contributing to in scientific capacity building and impact assessment as well as organizing annual consultation meetings among sorghum stakeholders, and by coordinating variety release procedures for India;
- The All-India Coordinated Small Millets Project will contribute to outputs 3.1, 3.2, and 3.3 by coordinating all activities for finger millet improvement in SA, including field trials to generate yield, and biotic/ abiotic resistance/tolerance data, and by contributing to in scientific capacity building and impact assessment as well as organizing annual consultation meetings among finger millet stakeholders, and by coordinating variety release procedures for India;
- Directorate for Wheat Research (DWR) coordinates wheat and barley research in India and will contribute to outputs 3.1, 3.2, 3.3, 3.4 and 3.5 by coordinating all activities for barley improvement in SA, including field trials to generate yield, and biotic/abiotic resistance/tolerance data, by contributing to in scientific capacity building and impact assessment as well as organizing annual consultation meetings among finger millet stakeholders, and by coordinating variety release procedures for India;
- The National Institute of Nutrition (NIN), Hyderabad, India, will contribute to output 3.5 by conducting studies on bioavailability of Fe and Zn studies of pearl millet grains and their value-added product;

- The Central Institute of Post Harvest Engineering and Technology (CIPHET), Ludhiana, India, will contribute to output 3.5 by developing and testing of prototypes of procedures and machinery for characterization of grains for processing traits such as hardness, efficiency of threshing, decortication, and milling, etc.;
- The Central Food Technological Research Institute (CFTRI), Mysore, India will contribute to output 3.5 by studying food system components (chemical, nutritional, toxicological, biomolecular, biophysical, microbiological, physiological and sensory profiling and food engineering), and by developing commercially viable processes and consumer friendly products. CFTRI will be involved in projects to understand the nutritional, functional and bioactive traits of pearl millet grains, as well as products developed from these grains.
- The Indian Institute of Crop Processing Technology (IICPT), Thanjavur, India, will contribute to output 3.5 by providing expertise both in post-harvest technology as well as food science and will be involved in developing and testing of prototypes that can be used to characterize the grains with respect to certain processing traits such as hardness, efficiency of threshing, decortication, milling etc., and also on nutritional and functional analysis;
- China, through its screening of barley Fusarium Head Blight nurseries and adaptation in Hangzhou and Shanghai, will contribute to outputs 3.1, 3.3, 3.4, 3.5;
- EIAR, Ethiopia will contribute to outputs 3.1, 3.2, 3.3, 3.4 and 3.5: by breeding and screening barley for netblotch, scald, powdery mildew, and stem rust, adaptation to several abiotic stresses; and by breeding and screening sorghum for Striga resistances, and production-specific biotic and abiotic stresses;
- NARO, Uganda, will contribute to outputs 3.1, 3.2, 3.3 by developing screening protocols and screening of sorghum and finger millet materials for its priority production systems;
- KARI, Kenya, will contribute to outputs 3.1, 3.2, 3.3 by developing screening protocols and screening sorghum and finger millet of materials for its priority production systems;
- Moi University in Kenya will contribute to output 3.2 by creating a sorghum locally adapted random mating population with increased frequency of alleles for Al tolerance, as well as phosphorus efficiency;
- DRD, Tanzania, will contribute to outputs 3.1, 3.2, 3.3 by developing screening protocols and screening of materials of sorghum pearl millet and finger millet for its priority production systems;
- Mozambique will contribute to outputs 3.1, 3.2, 3.3 by developing screening protocols and screening sorghum materials for its priority production systems;
- Zimbabwe will contribute to output 3.1, 3.2, and 3.3 by developing screening protocols and screening of sorghum materials for its priority production systems.
- Zambia will contribute to output 3.1, 3.2, and 3.3 by developing screening protocols and screening of sorghum materials especially for their respective priority production systems.
- Institut d'Economie Rurale (IER), Mali will contribute to outputs 3.1, 3.2, 3.3, 3.4 and 3.5 through its facilities and capacity for multi-location evaluation of sorghum and pearl millet breeding materials and experimental varieties, by screening sorghum and pearl millet for *Striga* resistance, as well as resistance for key diseases and insect pests. IER will also contribute its capacity for food technological observations on sorghum grain, as well its growing food processing business incubator, as well analytical capacity for fodder and feed qualities. IER is presently also coordinating variety release in close cooperation with LABOSEM, and the Ministry of Agriculture of Mali;
- Institut National d'Environement et Recherche Agricole (INERA), in Burkina Faso, will contribute to outputs 3.1, 3.2, 3.3, 3.4 and 3.5 by contributing facilities and capacity for multi-location evaluation of sorghum and pearl millet breeding materials and experimental

varieties, by screening sorghum and pearl millet for resistance to key diseases and insect pests;

- Institut National de Recherch Agricole au Niger (INRAN), in Niger, will contribute to outputs 3.1, 3.2, 3.3 3.4 and 3.5 by contributing facilities and capacity for multi-location evaluation of sorghum and pearl millet breeding materials and experimental varieties, by screening sorghum and pearl millet for resistance for key diseases and insect pests. INERA will also contribute its capacity for food technological observations on sorghum and pearl millet grain, as well its growing food processing business incubator.
- Lake Chad Research Institute (LCRI), Maiduguri, Nigeria, will contribute to outputs 3.1, 3.2, 3.3, 3.4 and 3.5 by contributing facilities and capacity for multi-location evaluation of pearl millet breeding materials and experimental varieties, by screening pearl millet for downy mildew resistance, as well as resistance to other important diseases and insect pests. LCRI will also contribute its capacity for food technological observations on pearl millet grain, and its growing food processing business incubator (in close collaboration with the University of Maiduguri), as well analytical capacity for fodder and feed qualities.
- Insititute for Agricultural Research (IAR), Samaru, Nigeria will contribute to all Strategic Objective 3 outputs relating to sorghum, as LCRI will do for pearl millet in Nigeria;
- Institut Senegalese de Recherche Agricole (ISRA), Dakar, Senegal will contribute outputs 3.1,.3.2, 3.3 as are other West African NARES. In collaboration with the Institut de Technology Alimentaire (ITA) at Dakar, Senegal they shall contribute to output 3.5;
- Similar collaboration exists with the Savannah Agricultural Research Institute (SARI), Tamale, Ghana for sorghum and pearl millet improvement;
- Makerere University, Uganda will contribute to output 3.3 by working on finger millet blast and training graduate students;
- Maseno University, Kenya will contribute to output 3.3 by working on finger millet blast and training graduate students;
- Egerton University, Kenya will contribute to output 3.3 by working on finger millet blast and training graduate students;
- University of Free State, South Africa will contribute to output 3.3 by training postgraduate students on different aspects of blast reaction;
- Regional bodies like ASARECA and CORAF facilitate networking among NARS with smaller sorghum, pearl millet or finger millet programs, and thus contribute primarily to output 3.1;
- COMESA and East African Community, INSAH (Institut du Sahel) and ECOWAS in West Africa will contribute to output 3.1 by facilitating the harmonization of policies, like seed policy, variety releases procedures, and trade policies;
- AGRA (Alliance for a Green Revolution in Africa) will contribute to outputs 3.1, 3.2, 3.3 and 3.5: by supporting NARES breeding programs in ESA and WCA that focus on dryland cereals; by providing advanced degree training to NARS who are working on dryland cereals; and by supporting private seed sector development in ESA and WCA.
- Iranian Agricultural Research, Education and Extension Organization (AREEO) will contribute to outputs 3.1., 3.2, 3.3, 3.4, 3.5 through: generation of barley lines and varieties adapted to the drylands and highlands of West Asia; its excellent laboratory facilities for food, feed analysis, controlled environment facilities for the analysis of abiotic stress tolerance (cold, salinity) at the Dryland Agricultural research Institute (DARI), Tabriz and Seed and Plant Improvement Institute of Iran (SPII), Karaj; and through doubled haploid production genetic analysis, and marker-assisted selection at the Agricultural Biotechnology Institute of Iran (ABRII), Karaj;

- The Institute National Agronomique de Tunisia (INAT) and National Agricultural Research Institute of Tunisia, Tunisia (INRAT) will contribute to outputs 3.1, 3.2 and 3.3 by screening barley for scald and BYDV, adaptation, and abiotic stress tolerance; the Centre de Biotechnololgy of Sfax (CBS) and Centre de Biotechnologie de Borj-Cédria (CBBC) will contribute to 3.2 and 3.3 through the application of biotechnological tools;
- The Institute National de la Recherché Agronomique (INRA), Morocco, will contribute to all Strategic Objective 3 outputs through screening for barley stem gall midge, testing barley germplasm for biotic and abiotic stress tolerance, adaptation and yield, and contributing laboratory analysis for marker assisted- selection and genetic analysis
- ICAMEX (Mexico) will contribute to all Strategic Objective 3 outputs through generation of barley lines and varieties adapted to the agro-ecological conditions and industrial needs of the State of Mexico;
- Ecuador and Peru will contribute to all Strategic Objective 3 outputs by screening for yellow rust, and providing laboratory facilities for the analysis of food and feed and malting quality.
- The two Hybrid Parents Research Consortia in India will be involved in Strategic Objective 3 activities in SA. They unite practically all relevant private breeding and seed companies working with dryland cereals, primarily sorghum and pearl millet, so individual companies are not listed separately here;
- The Sorghum Hybrid Parents Research Consortium in India will contribute to output 3.1 primarily and may contribute to the others based on economic opportunities and targets of specific members of the consortium by providing partial funding support for hybrid parents research, evaluation of trait specific nurseries/trials for field performance, hybrid development and marketing of hybrid seed (by the members of the consortium) and impact assessment;
- In much the same way, the Pearl Millet Hybrid Parents Research Consortium in India will contribute to output 3.1 primarily and may contribute to 3.2, 3.3, 3.4 and 3.5;
- Al Shark Malting Company (Syria) will be involved in the selection and testing of new malting barley varieties (objective 3.5);
- Seed companies in ESA (Namburi, Subra Agro, Tanzania; Victoria, Uganda and Kenya Seed, Kenya) will contribute to output 3.1 by identifying varieties for dissemination, in cooperation with Strategic Objective 6.
- Industrial grain processors (Unga, Kenya; Nyeri Farm, Tanzania and Maganjo millers, Uganda) and farmer groups will help with variety selection (output 3.1, and Strategic Objective 6);
- Kenya, Tanzania, Nigeria and Ghanaian malting and brewing companies will contribute to outputs 3.1 and 3.5 by identifying sorghum varieties adapted to their zones of grain sourcing, as well conducting specific grain quality analyses;
- Farmer organizations, such as: Fuma Gaskya and Mooriben in Niger; UGPCA (Union des groupement des producteurs pour la commercialisation agricole) and AMSP (Association Minim Song Panga) in Burkina Faso; and ULPC (Union Locale des Producteurs de Cereals de Dioila) and UACT (Union des Agricultuers du cercle de Tominian) in Mali will contribute to output 3.1 primarily, by conducting evaluations of breeding material and experimental varieties in their zones of action, as well as by producing and commercializing seed of preferred varieties;
- Agricultural development NGOs, like the Aga Khan Foundation (Mali), Action contre la Faim (Mali and Niger), as well as local NGOs like ASEDES and Adaf Galle in Mali and others, are seen as potential partners in achieving output 3.1, by evaluating experimental varieties;
- Large agricultural or integrated development projects in Burkina Faso (PDRD, funded by IFAD and AfDB), Niger (PPILDA, funded by IFAD) and Nigeria (CBARDP, funded by IFAD and others)

will also contribute to achieving output 3.1 by testing varieties on a large scale, and by following through with large scale seed production and dissemination (Strategic Objective 6).

Strategic Objective 4 - Developing sustainable crop, pest and disease management options to capture genetic gains from improved dryland cereal varieties and hybrids

Outputs, Methodology and Milestones

Output 4.1. Gender responsive crop management options to optimize crop productivity in smallholder farmer fields

The primary purpose of Output 4.1 is to provide technologies to farmers that are directly linked to maximizing the yield of existing cultivars and exploiting the genetic gains of new cultivars generated elsewhere in this CRP. Yield gap analysis shows very clearly that yield and production of dryland cereals can be increased, even by smallholder farmers in harsh environments, often with existing technology and at affordable prices (Cooper et al., 2009). These technologies include for example seed priming, micro-dosing, nutrient management, within field water management, reduced tillage and their interactions with cultivar in different farming systems. Water and fertilizer are regarded the major limitations to yield and are usually best dealt with in an integrated manner. Ex-ante modeling of crop management options will be used to target options in different systems and regions, and also to provide estimates of risk (Cooper et al., 2009). Likewise, analogue locations for climate variability and change will be used as testing and knowledge sites to develop and generate options, including building upon indigenous knowledge. Synergies will be sought with CRP 1.1 for testing new cultivars in integrated systems (e.g. conservation agriculture, crop-livestock-tree systems) and to ensure that products and their testing is gender-sensitive and appropriate for the targeted farming and livelihood systems. Women have an important role to play both as adopters of technology where they are farmers in their own right, and as farm laborers who undertake many crop management activities. Wherever possible, these technologies will be tested with/by male and female farmers using participatory methods such as the cluster based farmer field school CBFFS or Mother & Baby trials. Strategic local partnerships with extension agents or NGOs will be vital for this process, both as translators of technologies and information to farmers, and as change agents capable of delivering scaling-up at local and in some cases national and regional levels. These partnerships will by design involve other organizations in the impact pathway to address wider system issues and constraints; for example the need for input supplies chains for fertilizer.

Methodologies

Seed priming

Seed priming – soaking seeds in water for a pre-determined duration before surface drying and sowing, is a simple but proven technology that can increase resource-use efficiency (Harris, 2006). The benefits are greatest in drier more marginal environments (Harris et al., 2001). Seed priming can also be supplemented with micronutrients (e.g., zinc, molybdenum) and with starter doses of P, with low investment costs and low labor costs. Seed priming combined with microdosing has also proved very effective (Aune and Ousmane, 2011) and the low costs help farmers who are risk averse to consider this technology.

Site-specific nutrient management (SSNM)/integrated soil fertility management (ISFM)

Nutrient deficiencies are widespread in the SAT, with more than 70% of the fields in semi-arid tropics of India being deficient in key macro- and micronutrients. Likewise, in SSA, phosphorus (P) in particular is often deficient. In South Asia soil-test based nutrient application has proven very successful, raising yields across a wide range of states and systems. Water-use efficiency is also usually increased by the application of nutrients. However, nutrient × cultivar interactions have not been explored or exploited in SA and there maybe opportunities for higher nutrient use efficient cultivars. In SSA, ISFM and microdosing have been widely tested, with small quantities of organic (handful per planting basin) and/or inorganic (bottle top fertilizer per basin) fertilizer used to raise yields, even in drier years. There is some evidence that some cultivars respond better to microdosing than others and activities will be established to identify such cultivars.

Fertilizer microdosing

Microdosing of mineral fertilizers during critical growth stages for dryland cereals is proving to be an effective tool for increasing profitability of fertilizer for dryland cereals (Buerkert et al., 2001, 2002; Valluru et al., 2006, 2009; Karanam and Vadez, 2010). This approach is being taken up and disseminated on a large scale by AGRA and several large development actors in Africa. Participatory evaluation of fertilizer micro doses (small doses of fertilizers) will also be tested. Data will be collected on cost of all on farm activities and the cost of inputs and product outputs for a cost benefit analysis to establish the most profitable system and determining of optimal inputs combinations.

Crop water productivity improvement

Increasing the productivity of water means in its broadest sense, getting more value or benefit from each drop of water used (Kijne et al., 2003). Crop water productivity means raising crop yields per unit of water consumed. Crop water productivity varies with location, depending on such factors as cropping pattern, climate conditions, field water management, labor and fertilizer, e.g., water productivity of cereals other than rice range from 0.2-2.4kgs/cubic meter. Within field water capture and management technologies are available and there are a range of options for increasing water capture in field (as opposed to larger scale watershed capture which is under CRP 1.1 and CRP 5). These include tied ridges, zai pits, planting basins or semi-lunes, surface residue and contour farming. These will be tested in different farming systems and for the different dryland cereals

Cropping systems and cropping patterns

Cropping system refers to an arrangement in which various crops are grown together in the same field. The cropping systems followed in dry lands differ from those followed under better endowed conditions. Only those crops can be grown under dry land conditions which require less water to complete their life cycle or which can stand or yield under drought conditions. This can include drought resistant and drought tolerant species /cultivars. In addition, plants can be grown only where some water is available to sustain the growth of plants. Mixed cropping is also followed to minimize the effect of unpredictability of rain. Mixed cropping may have low yield potential but it works as a buffer against failure under possible unfavorable conditions. Mixed cropping may be defined as sowing of two or more crops simultaneously on the same piece of land in separate rows. Cropping pattern is defined as sequence of growing crops in a particular field at a particular period. The following recommendations should be followed for an efficient soil and water conservation targeting improved crop productivity:

- *Tillage requirements of the crops* – Tillage starts with the seedbed preparation and ends with mulching and control of weeds. Deep plowing during summer helps in destroying weeds and suppressing insect pests and diseases. It also helps in an efficient root penetration into soil. Placement of seed at 5 cm and fertilizers at 7.5 cm in the same furrow followed by soil compaction have resulted in better germination, plant vigor, extensive root development and higher crop yields.
- *Selection or crops and varieties* – There are a number of improved varieties of different crops that are drought tolerant or resistant to water stress. The most commonly grown crops in dry lands are sorghum, pearl millet, finger millet, wheat, barley, pulses, oilseeds, etc. The improved varieties of these crops are available in the targeted regions and countries for integration in the cropping system.

- *Sowing of crops* – Sowing of crops deals with several associated factors namely sowing time, method of sowing, and depth of sowing. Sowing time can markedly influence the production and productivity of dry land crops. Early sowing of rainy season crops results in early crop maturity and thereby it facilitates early sowing of succeeding post-rainy season crops. Early sowing of post-rainy season crops helps in overcoming the moisture stress at later stages of plant growth, particularly at grain filling stage. Broadcasting of seeds should be avoided as it involves several losses and seed does not properly come in contact with moisture. To get an ideal plant population it is necessary that about 25% higher than required seed rate should be applied. Care must be taken to reduce plant competition for moisture by removing excess plant population about 2-3 weeks after the sowing depending upon the crops.

Crop rotation

For resource-poor farmers engaged mainly in subsistence production, low-external-input technologies are usually a more affordable way to improve soil productivity. Crop Rotation is known as the practice of growing different crop in succession chiefly to preserve the productivity capacity of the soil. It is a system of cultivation where crops such as cereals and legumes that need different nutrients and/or management are grown one after the other. The advantages of rotating crops are firstly that pests particular to one crop are discouraged from building up and spreading, and secondly that some crops actually benefit the soil. Cereal /Legumes rotation can increase the nitrogen content of the soil if their roots are left in the soil after harvesting. If the rotation includes a ley, the system is known as alternative husbandry or mixed farming. Crop rotation is an essential part of weed management. It allows herbicide rotation and weed control by cultivation. Chemical control of grass weeds is best achieved in broadleaved crops. In cereals, adjusting sowing date, cultivations and herbicides all help to reduce problems with grass. Rotation can prevent carry-over and buildup of pests between susceptible crops. Crop rotation is also the first line of defense against diseases carry-over and development

Crop rotation can be integrated with compositing as an integrated fertility management approach. In addition, the potential of composting to turn on-farm waste materials into a farm resource makes it an attractive proposition. Composting offers several benefits such as enhanced soil fertility and soil health – thereby increased agricultural productivity, improved soil biodiversity, reduced ecological risks and a better environment. Even though the practice is well known, farmers in many parts of the world especially in developing countries find themselves at a disadvantage by not making the best use of organic recycling opportunities available to them, due to various constraints which among others include absence of efficient expeditious technology, long time span, intense labor, land and investment requirements, and economic aspects. The interventions points here would be to have diverse rotation plans which profitably meets market needs, manage soil, pests, diseases and weeds and suit the farms by crop/faming system and agro-ecology as well as the socio economic conditions of the farms families.

Integrated management options

Dryland Cereals with the exception of barley and finger millet are usually grown in combination with other food or cash crops – an association that minimizes risks, optimizes land use and maximize labor input per unit area of land. The dryland cereals are grown as a single crop, especially by large-scale farmers. In Ethiopia farmers mix faba bean in barley fields since they do not have enough land to allocate to the legume. Sorghum and Pearl millet are often intercropped/mixed cropped with legumes such as cowpea, green gram, pigeon peas, groundnuts, chickpea and lablab bean by smallholder farmers to provide the protein that supplement the carbohydrates and starch from the dryland cereals as well as animal fodder. Rural families invariably derive food, animal feed, and cash, together with spillover benefits to their farmlands for example in improving soil fertility through in situ decay of root residues and legume leaves. In addition, because the legume grain is widely traded out of the major production areas, it provides income and serves as a cheap and nutritious food for the relatively poor sections of urban communities. This Strategic Objective 4 will bring to the mainstream legume crops with inherent resilience to drought and hence enhance the food basket for households in the dry areas. There will also be close collaboration with the CRP 3.5 on Grain Legumes.

Milestones

- Studies conducted to identify available crop cultivars and management options for each dryland cereals per region and per farming system and a brochure of the same published and made available (2012)
- On-station and on-farm testing of different rates of micro-doses of fertilizers evaluated and optimum rates established and options for soil-water management demonstrated for each dryland cereals by region and farming system (2012)
- Training needs for stakeholders identified and disaggregated by gender (2012)
- Implementation of CBFFS for development and testing of integrated management of the main abiotic and biotic constraint(s) in two countries for two the two most important farming systems in each region (2013)
- Protocols for testing integrated crop cultivar and management using participatory approaches developed and tested to determine three methods for scaling out to other areas with similar production systems (2013)
- At least three best-bet crop management options identified using large-scale, gender-specific, farmer-participatory multi-location testing approaches for increasing hybrid productivity (grain and stover) in drought prone environments (2013)
- Location-specific improved production technologies tested (crop cultivars and soil-water-fertility management) for productivity and weed management (2014)
- Guidelines developed for optimization of soil fertility/organic matter management, including weeds, in at least three specific dryland cereal production systems, with varying levels of livestock integration (2014)
- Management options identified on a barley cropping system to minimize the detrimental effects of salinity (2014)

Output 4.2. Integrated Striga, disease, pest and weed management options to meet the social, environmental and ecological sensitivities of dryland cereals

Experience shows that the use of improved varieties alone is not adequate to attain the productivity levels required to meet farmers' food and income needs. Insect pests, Striga, diseases, non-parasitic weeds are serious constraints of dryland cereals productivity and production and utilization. Crop losses due to these pests have been estimated at over US$ 7.4 billion annually (Sharma 2006). *Striga*, grain molds, shoot fly, stem borers, midge and head bugs are important pests in sorghum across the SSA and SA regions whereas downy mildew, blast, stem borer and head miner are important in pearl millet. Finger millet blast and stem borers are important in SA and ESA and elsewhere where finger millet is produced. Chemical control of shoot and panicle feeding insects on cereals is beyond the reach of resource-poor farmers in the SSA, SA and CWANA. Current sensitivities about environmental pollution, human health, and pest resurgence are a consequence of improper use of synthetic pesticides. Host plant resistance, natural plant products, bio-pesticides, natural enemies, and agronomic practices are potentially viable options for integrated pest management (IPM). They are relatively safe for non-target organisms and human beings. Foliar disease including cereal rusts (mainly leaf, stripe (yellow) and stem rust), foliar diseases caused by Septoria leaf blotch (*Mycosphaerella graminicola*), leaf rust (*Puccinia hirdei*), and stem rust (*Puccinia graminis*) are widespread.

The new stem rust race Ug99 and its derivatives are considered as global threat to wheat and barley production. In experimental resistance screening at Njoro, Kenya more than 95% of barley genotypes from USDA and ICARDA were fully susceptible to Ug99 indicating vulnerability of barley varieties to Ug99. Despite the global efforts and supports given to wheat: rust research and development, there has been very little attention to the barley-rust pathosystem. Since the first detection in Uganda, Ug99 has been reported in Ethiopia, Sudan, Yemen and Iran. Other globally important foliar diseases of barley are scald (*Rhynchosporium secalis*), net blotch (*Pyrenophorateres*), leaf rust (*Pucciniahordei*), powdery mildew (*Erysiphe graminis* f. sp. *hordei*) and barley yellow dwarf virus. Crown and dry land root rot diseases caused by *Fusarium* spp. (*F. graminearum* and *F. culmorum*) are also important diseases of barley and wheat in the Maghreb countries. Research on this major barley disease has focused on identifying various sources of resistance. Sunn pest is the most widespread of cereal insect pest in CWANA. The term sunn pest refers to a group of insects representing several genera of the 'shield bug' (Scutelleridae) and 'stink bug' (Pentatomidae) Families, with the species *Eurygasterintegriceps* being the most economically important. Sunn pests are found in parts of North Africa, throughout West Asia and many of the New Independent States of Central Asia. The Russian wheat aphid (RWA), *Diuraphisnoxia* (Mordvilko), is a new insect pest of cereals in CWANA. The aphid injects a toxin into the plant that destroys the chloroplast membrane, causing total plant loss. Even though yield losses due to this pest have not been estimated, heavy plant damage has been observed, especially in dry years. A background to some of the critical issues and interventions points to address the same is given below:

Integrated striga management

Striga as a pest is difficult to control because of complex interactions between the host cereal, the parasite, the soil fertility and the cropping system. *Striga* develops into a serious problem when fields are continuously cropped with susceptible cereals and when the fields are not adequately fertilized. Various options exist for keeping *Striga* under control and below damaging levels, namely: (1) application of different types of organic fertilizers, (2) localized application of different types of mineral fertilizers, (3) rotating or (4) intercropping with non-cereal crops such as cowpea, groundnut, soybean, cotton, sesame or sorrel, (5) use of cereal varieties that are resistant or tolerant to *Striga* and/or low soil fertility, (6) frequent or timely weeding or hand pulling during early flowering of *Striga* (before it sheds its seeds), and (7) ridging and hilling around the cereal stands to cover up emerged *Striga* plants. Several other traditional control methods exist, such as the treatment of seeds with dried fruit powder of locust bean tree (*Parkia biglobosa*) or Baobab (*Adansonia digitata*) dried leaf powder, as well as localized application of ash (by burning stalks in spots where *Striga* plant density was high the previous year). Although familiar with some of these options, most farmers in West Africa tend to implement only one or two at the most of these options, while a combination of methods would be far more effective for dealing with *Striga* and soil fertility. Even those farmers who are aware of a range of traditional and ‘modern’ options for managing *Striga* and soil fertility seldom implement an integrated approach. But by resorting to as many different options as is practical under the local circumstances, it is indeed possible for a farmer to achieve efficient *Striga* control and thus bring about improved crop yields, increased profitability, and long-term reduction of the *Striga* seed bank in conjunction with increased soil fertility.

There are two main obstacles preventing farmers in sub-Saharan Africa from efficiently combining their strategies and effectively managing *Striga*. Firstly, most farmers lack the necessary understanding of *Striga* biology: how it parasitizes and affects the host cereal, how it reproduces and how it spreads. Secondly, many farmers are not aware of all the different options available for controlling *Striga* or minimizing its negative effects. Equipped with this knowledge, a farmer is automatically in a better position to make more practical decisions on how to manage a field with *Striga* infestation and a poor soil.

The CBFFS approach mentioned above will allow for the development of site-specific combinations and adaptation of the options available to farmers and a participatory evaluation of these options. The CBFFS system at the same time permits many farmers to participate in the development, testing and evaluation of integrated Striga management and actively encourage farmer-to-farmer extension and knowledge sharing.

Integrated pest management

Several management practices have been developed and tested in farmers' fields. Farmers both in Africa and Asia have adopted components of IPM packages. Major successes, for example are in pearl millet, where HPR and seed dressing with metalaxyl has significantly reduced the incidence of downy mildew. This simple technology has helped increase millet yield and farmers' incomes in Mali. In India, many private seed companies treat pearl millet hybrid seed with metalaxyl to protect the crop from downy mildew and prolong the commercial life of hybrids. However, there is a need for the judicious use of fungicide in combination with host plant resistance to avoid the emergence of fungicide-resistant strains of the pathogen. Natural enemies are important in the control of major insect pests and are an important component for the management of stem borers and armyworm. Quantifying the effect of borer-resistant cultivars and effectiveness of natural enemies will be a major concern in future pest management programs. In addition, natural plant products and biopesticides offer a potentially viable alternative to synthetic insecticides since they are relatively safe to natural enemies, non-target organisms, and human health.

Natural enemies

Natural enemies are important in the control of major insect pests. Natural enemies are an important component for the management of stem borers and armyworm. Quantifying the effect of borer-resistant cultivars and effectiveness of natural enemies will be a major concern in future pest management programs.

Bio-pesticides

Current sensitivities on environmental pollution, human health hazards and pest resurgence are a consequence of improper use of synthetic pesticides. Natural plant products and bio-pesticides offer a potentially viable alternative to synthetic insecticides since they are relatively safe to natural enemies, non-target organisms, and human health. There have recently been exciting developments in the field of natural products for pest management. Several bacterial and fungal isolates have been identified as potential bio-control agents. Effective integration of HPR, agronomic strategies and alternative natural pesticides requires an analysis of multi-trophic interactions in the context of benefits versus crop damage and yield loss. There has been tremendous interest from public and private institutions, both national and international, in natural plant products. New cultural practices that can reduce pest incidence and damage need to be investigated. Bio-pesticides (both botanicals and microorganisms) identified earlier as promising were used for crop protection under field conditions. This also involved reduced use of urea, and use of trap crops and intercrops. The expertise gained was shared with the bio-fertilizer/bio-pesticide industry in India, with a view to developing public-private partnerships for bio-pesticide research.

Judicious use of pesticides

Pesticides are still the most reliable and economic way of protecting crops from pests. While accepting this, we need to find ways to maximize the efficacy of pesticide use, while minimizing harmful effects on the environment, and slowing down or reversing the rate of development of resistance in target pest species. Efforts have been made in the past to implement insecticide resistance management strategies in cotton in several parts of the world – but no attention has been paid to resistance management and efficacy of control operations in other crops that play an important role in pest population dynamics. Therefore, pest management efforts should focus on developing a comprehensive approach to the management of these pests that affect DC. Adequate knowledge of economic importance, farmer perceptions of pest losses, harmful effects of insecticides on the environment, and the potential benefits of IPM technologies for sustainable crop production is critical for setting priorities and making rational decisions on pest management. Several chemical control methods for *Striga* were evaluated – fumigants, germination stimulants, antitranspirants, seed hardening, seed treatments and herbicides. It was concluded that of these methods, the use of herbicides is best suited for *Striga* control. Evaluation of new herbicide formulations will remain an important activity. In addition, collaboration with farming-systems teams is important to develop control technologies that are adapted to local conditions, and economically feasible.

Methodology

Insect and disease modeling, decision support systems, and remote sensing could contribute to up-scaling and dissemination of IPM and IDM technologies. Therefore, already developed integrated crop management options will be tested and validated in combination with available varieties as a key strategy to enhance crop productivity. This will include *striga* and weed management, and validation of integrated improved varieties with crop and fertility management options. The most cost effective technological combination options will be identified. Farmer-participatory approach will be the main strategy for technology testing. This approach will bring men and women farmers close to the technology during the development and validation stages and their feedback will be used in recommending appropriate technologies for release and widespread dissemination for adoption. Weed management, while being the primary bottleneck for yield increases for smallholder farmers, has been neglected by researchers in recent years. As patents for key herbicides (such as glyphosate and atrazine) have expired, their availability and use in dryland cereal production areas is increasing, in many areas without technical guidance or insights. Research support is thus needed to guide safe and efficient use, and to develop alternative options. A similar situation presents itself with respect to seed treatments. Emergence of specific pesticide resistant strains will be closely monitored and new molecules with diverse mode of action will be identified. The parasitic weed *Striga* is of particular importance in poor soil conditions and its control requires integrated genetic and crop-management interventions. A suite of crop management options have been identified that contribute to S*triga* control and local choice of specific components through farmer participatory processes is ongoing and will be enhanced. Several bacterial and fungal isolates have been identified as potential bio-control agents. Effective integration of HPR, agronomic strategies and alternative natural pesticides requires an analysis of multi-trophic interactions in the context of benefits versus crop damage and yield loss. There has been tremendous interest from public and private institutions, both national and international, in natural plant products. New cultural practices that can reduce pest incidence and damage will be investigated. Bio-pesticides (both botanicals and microorganisms) identified earlier as promising will be used for crop protection under field conditions. In addition, interaction of micronutrients, bio-agents and host genotype will be studied to select the nutrient and bio-agent combinations that provide enhanced levels of resistance in the host to the key pests.

Milestones

- CBFFS for development and testing of integrated management of *Striga* and soil fertility in at least two countries for the two most important farming systems in each region (WCA and ESA) (2012)
- Intensive training on IPM and IDM options conducted with special emphasis on bio-pesticide production and utilization for at least three crop pest/disease combinations in specific production ecologies (2012)
- Integrated management of Russian wheat aphid on barley developed and tested in two countries for the CWANA and ESA each regions for the dryland cereals infested by striga (2012)
- Integrated shoot fly management options fine tuned for various production areas (2013

- Weed management options compared in at least two farming systems, disaggregated by gender needs, including monitoring health and environmental effects of increasing herbicide use in dryland cereal cultivation (2013)
- 200 farmers/country participate in Farmers Field Schools (FFS) on integrated Aphid management on barley in Ethiopia and Eritrea (2013)
- Interaction of nutrients and bio-agents with host genotype studied to select combinations that elicit systemic resistance against the key pests in sorghum and pearl millet (2014)
- Integrated *Striga* management options developed and tested in ESA and WCA, and shared with the NARS partners and integrated shoot fly management options fine tuned for various production areas (2014)
- IPM/IDM systems for the management for at least three crop pest/disease combinations developed for specific production ecologies (2014)
- Lessons learned and best practices for effective large-scale participatory integrated crop management practices published, and selected women and men farmers' knowledge in assessing the cultivars and management practices enhanced (2014)

Partners and their Roles
Strategic Objective 4 partners will be based primarily on the ability of each to make significant and timely contributions to the activities in which they are involved. NARES and NGOs that often work with the different CG centers in evaluating new crop management practices will be extensively involved, as will ARIs and the private sector organizations with a strong interest in developing crop management options for dryland cereals:

- ICRISAT will contribute to outputs 4.1 and 4.2 by:
  - Collating and publishing available crop cultivars and management options for further testing across the different farming systems;
  - Developing protocols and designing on-station and on-farm trials for testing individual and integrated crop cultivars and management technological combinations;
  - Data analysis and synthesis to identify best bet integrated crop management options for scaling out
  - Identifying training needs for all stakeholder groups and organize/explore partners to provide the required capacity for better crop management options for the DC (for 4.1 and 4.2);
  - Testing practicality of DC seed priming in the different farming systems and feasibility to supplement it with micronutrients and study its impacts on grain micronutrients contents;
  - Establishing crop water productivity for the 3 crops as affected by cultivars, cropping patterns, climatic conditions, field water management, labor and fertilizer;
  - Collating and synthesizing data from site specific nutrient microdosing trials;
  - Synthesizing and publish gender concerns in dryland cereal crop management and identified technologies and strategies a that are gender responsive and women-use friendly;
  - Providing intensive training on IPM and IDM with emphasis on production and utilization of bio-pesticides for the 3 crops and different farming systems;
  - Develop protocols and fine tune shoot fly management option in the targeted farming systems;
  - Identify and test a wide range of bio-pesticide for their effectiveness in pest control;
  - Develop ISM options and organize for testing targeting the 3 crops and different farming systems;

- Testing different herbicide formulations for effectiveness in controlling weeds in each of the 3 crops in the different farming systems;
- Conducting studies on interactions of nutrients and bio-agents to select combinations that elicit systemic resistance against key pests for the 3 crops;
- Monitoring health and environment effects on increasing herbicide use in the three crops
- Enhancing utilization of men's and women's knowledge in assessing cultivars and management practices; and
- Publishing lessons learned and best practices for integrated crop management and approaches for scaling out.

▪ ICARDA will contribute to outputs 4.1 and 4.2 by:

- Identifying and publish available barley varieties and management options for testing across the different farming systems;
- Developing protocols and design on station and on farm trials for testing individual and integrated crop varieties and management technological combinations for managing salinity in barley dryland farming;
- Data analysis and synthesis to identify best bet integrated crop management options for scaling out;
- Identifying training needs for all stakeholder groups and organize/explore partners to provide the required capacity for better barley crop management options;
- Identifying best barley cropping sequence for the different barley farming systems to minimize the detrimental effects of salinity;
- Establishing barley crop water productivity as affected by varieties, cropping patterns, climatic conditions, field water management, labor and fertilizer;
- Synthesizing and publishing gender concerns in barley crop management and validate the gender responsiveness and women-use friendliness of the technologies;
- Developing protocols for testing integrated management options of Russian wheat aphid on barley;
- Developing protocols for testing integrated aphid management on barley in Ethiopia and Eritrea using FFS;
- Monitoring health and environment effects of increasing herbicide use in barley cultivation;
- Publishing lessons learned and best practices for integrated crop management and approaches for scaling out;
- Enhancing utilization of men's and women's knowledge in assessing barley varieties and management practices; and
- Publishing lessons learned and best practices for integrated crop management and approaches for scaling out.

▪ NARES in WCA, ESA, CWANA, SA will contribute to 4.1 and 4.2 by:

- Implementing crop management on farm and on station trials on the respective crops and in the targeted farming systems as per agreed protocols and procedures;
- Production of agronomic, performance, environmental; and input price information for building a geospatial information bank;
- Promoting and scaling up and out the integrated crop management options as informed by geo-spatial tools;
- Conduct crop management demonstrations, e.g., on seed/fertilizer/herbicide in collaboration with farmers;

- Providing gender disaggregated feedback from collaborating partners to facilitating fine tuning of technologies; and
- Lobby/advocate for policy support in adoption of new technologies such as microdosing.

▪ ARIs will contribute to 4.1 and 4.2 by:

- Providing expertise in geospatial modeling, In collaboration with ICRISAT and ICARDA; and
- Conducting capacity building, especially postgraduate training that is linked to dryland cereals (INTSORMIL is seen as a particularly important partner here).

▪ Private sector organizations will contribute to 4.1 and 4.2 in several ways:

- Agro-dealers at community, regional and national level will facilitate easy access to inputs such as fertilizer, herbicides and pesticides;
- Agro dealers will be linked to national input subsidies to avail inputs at subsidized and affordable prices where such schemes are operational;
- Support the use of inputs such as fertilizer by linking input with output marketing, e.g., processors of food, feed and beverages (breweries);
- Facilitate uptake of fertilizer by encouraging agro dealers to enhance small packs of fertilizer and herbicides, e.g., Monsanto now sells small packs (100 gram sachets) of roundup and Dow are marketing 50 g sachets of Spintor dust for control of weevils; and
- Encourage grades and standards of grain by offering premium prices for high quality, e.g., disease free products.

▪ NGOs will contribute to 4.1 and 4.2, as well:

- International Fertilizer Development Cooperation (IFDC) will help in promotion of fertilizer use;
- Conduct capacity building on fertilizer use;
- Farm Inputs Promotions (FIPs) and agro dealers will:
  - Promote usage of small packs of fertilizer along with improved seeds, improve farmers understanding of different fertilizer blends;
  - Train agro dealers in book keeping and stock management and in advising farmers the type of fertilizer to use;
  - Develop protocols for identifying nutrients limiting productivity; and
  - Raise awareness among farmers on the potentials for using fertilizers.

▪ CBOs and farmers (and their organizations) will contribute to 4.1 and 4.2 by:

- Providing feedback and lessons learned over the years on factors most limiting productivity; and
- Using mini-packs and simple protocols, farmers (men and women) will conduct farmer managed on farm trials to identify best bet crop management technological options

STRATEGIC OBJECTIVE 5 - ENHANCING EFFECTIVE SEED AND INFORMATION SYSTEMS FOR BETTER DELIVERY OF IMPROVED TECHNOLOGY PACKAGES TO SMALLHOLDER FARMERS

Outputs, Methodology and Milestones

Output 5.1. Integrated technology packages for dryland cereals

In order to increase yield and adoption in farmer's fields, varieties need to be diffused together with appropriate and improved crop management practices that can integrate in to farmers' production systems. It is understood that in many of the dryland cereal production systems, soil fertility and water management are the key to improving production (grain and stover/straw). In most of SSA, it is usually not a single factor that reduces yield, but multiple factors that lead all together to the observed yield reductions (i.e., a combination of factors such as striga, low soil fertility and drought; late planting, midge and possibly drought). Agricultural technology packages also need to be tailored to the different socio-economic conditions of each region. They also should respond to gender differences. For example, developing integrated technologies such as microdosing to improve soil fertility, integrated striga and soil fertility management (ISFM) and headminer management, agronomic management of cereal legumes associations are crucial. Microdosing of mineral fertilizers during critical growth stages for dryland cereals is proving to be an effective tool for increasing profitability of fertilizer for dryland cereals (Buerkert et al., 2001, 2002; Valluru et al., 2006, 2009; Karanamand Vadez, 2010).

Methodology
The approach includes participatory technology selection with farmers and economic evaluation of technology packages coupled with adoption studies of the new technologies by farmers. The approach combines three levels: participatory technology development with farmers, economic evaluation of technology packages and adoption studies of the technology packages.

Participatory technology development: From the outset, diagnostic surveys will be carried out to identify constraints of cropping systems to guide the choice of technologies for testing schemes. Once constraints have been identified participatory approached will be employed to evaluate the new technologies with farmers for example using Farmer Field School approaches for ISFM in countries like Mali, Nigeria and Burkina Faso. Large number of mini-kit variety trials could also be conducted to introduce farmers with new varieties and associated technologies in collaboration with partner organizations (NGOs, farmer organizations). Furthermore demonstrations of varieties and hybrids will be linked to input suppliers. It is also possible to evaluate varieties (groundnut or cowpea associations) in West Africa particularly targeting women farmers.

Economic evaluation of technology packages: The newly introduced integrated technology packages will be evaluated in farmer's fields. Therefore the cost benefits for application of ISFM and other crop management (micro-dosing, compost production and application, etc.) practices will be monitored and evaluated with farmers. In order to measure changes baseline surveys will be conducted to determine benchmark indicators against which achievements or changes would be measured.

Adoption studies of technology packages: Farmers adoption of new technology and its diffusion is monitored technological changes documented. Ex-ante and ex-post adoption studies would be conducted to identify likely factors influencing adoption and provide appropriate policy recommendations.

Milestones
- Variety and hybrid demonstrations linked to input suppliers in SSA (2012)
- Integrated technology packages tested in three regions tested (2014).
- At least one technology package specifically adapted to meet women farmers' needs in each region developed (2014)
- Economic evaluation for integrated technology packages completed (2014)
- Impact assessment for one cereal crop in each region conducted (2014)

Output 5.2. Innovations to strengthen seed and input delivery systems

In most of the developing world, the agricultural sector remains a public domain in terms of research and seed delivery. Past efforts in strengthening the public agricultural research and seed delivery along the 'seed chain' remain limited and focus on seed supply side lacking market-orientation. Inherently weak institutional linkages along the chain, in which different and sometimes independent institutions handle variety development, seed production, seed marketing and seed extension, is an impediment to progress (Bishaw and Kugbei, 1997). The success of seed industry however has often resulted from integration of agricultural research, production technology, input supply, market support, and extension information driven by the private sector. For example, private seed companies tend to reduce transaction costs through vertical integration of research-seed production-seed distribution continuum to recoup their investments (Morris, 2002). These realities call for a paradigm shift in seed sector development that favors liberalization, deregulation and diversification to promote the emergence of competitive seed industry that aims to satisfy the need of broad range of farmer groups.

The dryland cereals seed sector is at different stages of development in different countries, and within and among regions. While sorghum and millet hybrid seed technology took root in India, the dryland formal seed sector is non-existent in many countries of Sub-Saharan Africa. Comparative and critical assessments of the status of the seed sector of dryland cereals and case studies in selected countries would help to draw lessons and design alternative models. Fast tracking variety release linked to variety popularization and accelerated seed multiplication will reduce the time lag between variety release and availability of and access to seed of new varieties and its adoption by farmers (Osborn and Bishaw, 2010). Lack of institutional arrangements and functional seed units due to inadequate capacity and infrastructure is exacerbating the problem and hindering quick access to seed of new crop varieties by public and private seed producers and ultimately by the farmers. Lack of seed infrastructure or equipment is not only restricted to NARS for early generation seed production, but also equally apply to both the existing public seed enterprises, emerging private sector and local level seed initiatives for certified seed production and regulatory agencies where critical needs assessment are necessary to increase capacity in seed production and marketing (Bishaw and Kugbei et al., 1997).

Understanding the seed market is essential to identify determinants for seed demand of improved varieties. An assessment of the seed market will be conducted to measure the volume of the seed market than purely focusing on seed supply side. Critical analyses of technical efficiency and marketing capacity of public- and private-sector seed producers is also important to develop alternative models (centralized or decentralized) for certified seed delivery of dryland cereals. Restructuring large public seed sector into autonomous centers have been tried in some countries for self-pollinated crops (Zakhary and Ismail, 1997). Moreover, any alternative seed delivery model envisaged should be technically feasible and economically viable to ensure sustainability of the seed business (Srinivas et al., 2010). The diversification of the seed sector requires enabling policies and regulatory frameworks that are flexible and inclusive of all stakeholders. Lack of participation, flexibility, efficiency and transparency in variety release, seed certification, etc., appears to be problematic (Tripp, 1999). Policies and procedures should be reformed internally and harmonized regionally to create better choices for farmers by accelerating varietal release and access to seed.

Similarly, a review of input delivery systems should be made in terms of policy and institutional arrangements and marketing services to identify constraints (credit, etc.) that hinder availability and access, and to provide recommendations for improvement.

Methodology

The aim of this work will be to assess the functioning of seed systems in order to derive successful models with potential spillovers for adaptation to specific country situations. The variation in seed sector development among countries will provide a wealth of information for comparative analysis, with lessons learned being used to design better seed delivery options. A number of case studies would be employed targeting some countries where policy reforms made tremendous impact through private sector participation (e.g. in India) and where the policy lags behind and the public sector continue to dominate the seed sector in several countries in Africa. For dryland cereals, despite the availability of improved varieties in some countries, it is yet unclear whether lack of effective demand or lack of seed is the foremost constraint (Diakité et al., 2008). Country case studies will be conducted on the technical efficiency of seed production and marketing in countries where the public sector remain to dominate the seed sector in Africa (e.g., East Africa, North Africa, West Africa) to identify critical bottlenecks for improvement. Understanding the seed markets and developing effective distribution networks involving local agro-input dealers or traders or developing alternative innovative options where infrastructure is limiting to reach farmers remain critical in building seed delivery. In addition, needs assessments for critical infrastructure must be made to strengthen the capacity of the public and emerging private sectors including farmer-based seed production and marketing units to enhance the availability, access and use of seed of new dryland cereal varieties at the farm level.

In the absence of formal seed delivery, a broad range of local seed production enterprises have been initiated and implemented by development projects and NGOs (Thijssen et al., 2010). Information is limited as to the sustainability of such initiatives once external support is completed. Selected case studies will provide insights on technical performance and sustainability of local-level seed production involving farming communities. Furthermore the functioning of informal seed sectors will be studied to understand farmers' local knowledge and management of seed. The lessons from reviews and studies will help to design alternative seed production and marketing models (e.g. village-based seed enterprises) that are 'owned' and managed by farmers (Tavva et al., 2010). These enterprises, established through multi-stakeholder processes, will be provided with key facilities (e.g. mobile cleaners, storage facilities), trained in technical aspects and business management, and linked to formal sector institutions (e.g. for source seed, etc.). These pilot alternative seed/input delivery models will be monitored and evaluated for their profitability and sustainability.

In another effort using variety trials and variety test kits as innovations will be initiated to sustain seed delivery systems (continuous choice of varietal diversity) by combining variety test kits trials and seed production and marketing efforts to improve farmers' access to new varieties as well as combining variety testing and seed diffusion through mini-pack sales.

In recent years, while technological or market dimensions took center stage in investment for seed sector, the policy debate has been largely ignored and needs to be integrated (Alemu, 2010). Rationalizing and harmonizing of policy and regulatory frameworks pertaining to variety release mechanisms, IPRs, seed certification schemes, phytosanitary measures and biosafety issues will require multi-stakeholders consultation process within and between countries in the region.

This would facilitate cross-border movement of varieties and seeds within and between economic trading blocks and create opportunities for the domestic and foreign seed companies to enter regional seed markets, particularly in areas where commercial opportunities exist. Harmonization may promote the expansion of national and regional seed industries by stimulating the private sector investment (Rohrbach and Howard, 2004) allowing the flow of varieties emerged from international collaborative research. Efforts should be made building on already existing initiatives in SSA (SADC, ECOWAS, and COMESA) and CWANA (ECO) regions for the integration of the seed sector.

Milestones

- Review of existing alternative seed delivery models conducted and results made available, and technically and economically viable pilot farmer-based seed production and marketing enterprises established and their sustainability evaluated in at least one country in each region (2012-13)
- An in-depth analysis of national seed system for dryland cereals completed in at least one country in each region and lessons drawn and recommendations made to national governments (2013-14)
- Review of early generation seed production completed and functional seed units and procedures established in at least one country in each region to ensure availability and access to foundation seed working with public sector, seed cooperatives and private sector (2012-13)

- Review of infrastructure and equipment needs completed in at least one country in each region and critical needs addressed in partnership with development partners and personnel trained in seed science and technology (2013-14)
- National studies on the technical efficiency of public- and private-sector dryland cereals seed production completed in at least one country in each region including seed cooperatives in Mali, Burkina Faso in WA (2012-14)
- Support to harmonized regulatory framework on variety release, seed certification, phytosanitary measures, etc. within regional economic blocks (COMESA, ECOWAS, SADC, etc.) implemented (2014-15)
- Existing agricultural input supply systems (fertilizers, etc.) is conducted, results become available and systems strengthened to increase farmer access to inputs for dryland cereals in Mali, Niger, Burkina (2013)
- Assess the efficiency of diffusion schemes targeted on women (2012)

Output 5.3. Better communication and knowledge sharing for improved awareness and use of dryland cereal technologies

The majority of farmers, especially smallholder farmers, still do not benefit fully from the information and knowledge generated by Centers and partners. This is attributable partly to poor agricultural extension systems and limited, uncoordinated international and national support for knowledge dissemination, and partly to the limited capacity of national programs to take advantage of advances in information and communication technologies (ICT) in order to acquire, manage and disseminate knowledge. The communications strategy and action plan for this project will be developed in a consultative process that is part of the research planning process and linked to the monitoring and evaluation framework. The strategy and plan will be designed to get research and the new ideas generated, into use as a part of the program's research project cycle – defining specific activities, outputs and outcomes planned during the program. The approach will be based on action plans for ***strategic communication*** – engaging specific groups of people to achieve a specific, defined, result; and ***knowledge sharing*** – sharing experience and learning together as a part of the project, both among the project team and with partners, and capturing and sharing this learning as the program progresses.

Farmers, agricultural officers and scientists need awareness on improved crop varieties and production technologies. However, a CTA (Technical Centre for Agricultural and Rural Cooperation) sponsored study has identified variation in agricultural information among institution within countries and the common priority information needs across institutions (Assigbley and Kebede, 2009). CRP 3.6 recognizes that it must improve its learning capacity, in tandem with its partners, to put research results into use by improving the capacity of national agricultural extension systems and enhancing information delivery using conventional and modern ICT tools. The strong partnership and co-learning processes of knowledge management an dissemination would allow and motivate the rural poor to share the responsibility and decision making process and will allow the communities to negotiate action plans that reflect their priority needs for approaches and technical, institutional and policy options that enhance their livelihoods.

Rural radio appears to be an effective means to diffuse information to farmers, as they operate in all regions and use local languages. Farmers are learning about agricultural issues as well as market price information. Farmer cooperatives in Niger estimate that more than 50% and in some regions up to 90% of seed sales are due to information broadcasted in the local radio (Dr. Ignatius Angarawai, pers. Comm.). Video messages are another means to diffuse information on a large scale. Several farmer organizations and NGOs were trained in Mali and Niger to produce farmer-to-farmer video messages

Methodology

The ideal way to design the strategy is in a special communication workshop to design an "influence pathway" and specific outcomes for each key group, and a series of outcomes that the program will target to engage with these groups and achieve the planned results. This process will make clear the types of information products and services that the program and its communications plan need to produce to achieve the desired outcomes. These will include: special meetings, targeted information campaigns, specific types of documents (policy, technical, and media information), activities to engage and influence policy makers and extension staff, building the capacity of seed systems managers in countries, exchanging knowledge and experience from the research through case studies and relevant internet resources. The workshop will result in a shared vision by research leaders on the communication goals and priorities of the program, and an action plan, developed together my program management and relevant partners, with a clear indication of what is to be done and who is responsible for implementing communication and knowledge sharing activities for the program on effective seed and information delivery systems.

The CRP will help develop the capacity of national and regional systems to benefit from advances in information and communication technologies, enabling them to store and retrieve data effectively and to promote knowledge sharing between stakeholders – farming and herding communities, civil society organizations, NARS, donors and ministries. It considers how the stakeholders (rural communities, public and private sectors, scientists, civil society organizations, etc.) can be brought together in coalitions to facilitate mainstreaming of up-scaling, out-scaling, of verified key agricultural knowledge and technologies. This involves designing and operating an information repository system that is accessible to users by collating, analyzing, assembling, storing and retrieving agricultural information on crop varieties and agricultural production technologies, agricultural inputs and agricultural produce markets. The need for developing the skills of the ICM staff particularly revolves around developing and managing websites, databases, and networks; application of ICTs in agricultural communication; packaging of information in a language and format appropriate to target audiences; and the development and implementation of ICM policies and strategies (Assigbley and Kebde, 2009).

These efforts could be augmented with training in how to use rural radios to diffuse information on seed, variety tests and mini-pack availability. In addition, training in producing video messages on agricultural issues in local languages should be done and other information delivery systems using technologies easily accessible for farmers should be explored, such as mobile telephone information systems

Milestones

- Agricultural extension systems reviewed, key gaps identified and recommendation made to NARS (2012-13)
- ICM policies and strategies for agriculture and rural development sector formulated and implemented (2012-13)
- Web-based information repository on seed sector including variety catalogues, field and seed standards, directory of key seed sector stakeholders, etc. initiated along coupled with newsletter for sharing information and creating awareness across the regions (2014)
- Develop web-based information repository on agricultural technologies for dryland cereal production and shared on open and collaborative mode (2014)
- Market information system for agricultural inputs developed including fertilizer providers, etc. (2014)
- Market information system for agricultural products developed including dryland cereals products, agro-processors, etc. (2014)
- Train farmer organizations, NGOs and NARES in developing and producing radio and video messages

Partners and Their Roles

The major research and/or development partners include:

- National agricultural research systems and sub-regional research organizations will work with international crop improvement centers to develop well-adapted and farmer-preferred dryland cereal varieties and provide early generation seed (breeder and foundation seed).
- National agricultural extension systems, working with key national partners, will promote improved dryland cereal varieties and appropriate crop management practices.
- National seed regulatory agencies dealing with crop variety release mechanisms, seed certification schemes, phytosanitary measures and biosafety protocols will focus on enhancing varietal and seed choices for farmers.
- Public sector organizations, emerging domestic private sector companies, and local farmer-based seed enterprises (farmer groups, cooperatives) involved in dryland cereals seed production and marketing will strive to ensure availability of and access to seed of new varieties.
- National and regional seed trade associations representing the interests of the seed industry in their respective countries and regions will encourage private sector investment in commercial seed markets.
- Regional blocs (COMESA, SADC, ECOWAS, etc.) advocating economic integration will work with international development partners (such as FAO, OECD, ISTA, ISF, UPOV, and various NGOs) to promote harmonized procedures in seed sector development.
- National networks of agro-input dealers will be tapped to supply agricultural inputs and services to farmers.
- National and regional agro-industries involved in dryland cereals processing and marketing creating demand for sorghum products and stimulating farmers investment in production of dryland cereals

STRATEGIC OBJECTIVE 6 - ADDING POST-HARVEST VALUE AND IMPROVING MARKET ACCESS OF DRYLAND CEREALS TO PROVIDE SMALLHOLDER FARMERS MORE BENEFITS FROM DRYLAND CEREALS

Outputs, Methodology and Milestones

Output 6.1. Improved storage and processing technologies to reduce post-harvest losses in quantity and quality

For effective storage of grains after harvesting, proper drying is considered to be one of the important factors. Grains are often heaped on the field after harvesting for drying or shifted to a drying yard. With these methods, there is a lack of air movement, leading to sprouting, discoloration and microbial damage resulting in deterioration of grain quality. In addition, the grain is exposed to spoilage by rodents, birds and insects. Thus, effective and affordable drying technologies and practices need to be identified and implemented. Further, in most cases threshing is done by hand and involves women. The panicles are either placed in bags or kept on a threshing platform and then beaten repeatedly with long sticks until the grains are separated. In some cases, cattle are used for threshing. Such methods are inefficient, slow, laborious and complete recovery of grain is not achieved. Losses occur during threshing by spillage; incomplete removal of grain from stalks; by damage to the grain during threshing, by poor separation of grain cleaning or winnowing after threshing (Hamilton, 1980). The grain and chaff are then gathered together and hand winnowed using small winnows. Appropriate storage of grains after harvesting is an important post-harvest operation that also contributes to the post-harvest losses is attributed to the lack of appropriate storage technologies and practices. A recent FAO study reports post-harvest losses of sorghum and millet to be 6% in Mozambique (FAO, 2010). A major amount of losses is attributed to the lack of appropriate storage technologies and practices. During storage, grain is also subjected to qualitative and quantitative losses due to several agents including insects, fungi, rodents and mites. Insects and rodents eat the grain and also contaminate the grain with their eggs, exoskeleton (insects) droppings, hairs and urine in the case of rodents. Traditional methods of treating grains are widespread, but may not be always effective.

Methodology

Among the various drying methods previously tested, affordable solar dryers need to be explored and designed, along with improved conventional and other non-conventional options for drying of grain after harvesting. Such dryers must be tested at the farm level for the respective farm produce. Economic feasibility in terms of machinery and processing costs, energy efficiency and end grain nutritional quality shall be the deciding parameters in the final selection of the appropriate drying technology. Appropriate farm-level drying yards to minimize pest and microbial losses will be studied. Threshing, winnowing, grading and decorticating pearl millet and sorghum are important post-harvest activities, and traditionally involve women. Development of suitable prototype devices, for the above-mentioned post-harvest operations, suited for smallholder farm operations will be an important research and development activity. The activity will focus on developing prototypes having ease of operation, processing capacity, and ability to efficiently produce clean, unbroken, quality grains. Most importantly the processing steps and prototypes to be used will be evaluated based on cost-benefit analysis.

Prototypes will be designed in order to deliver higher capacity and superior quality as compared to traditional threshing, winnowing processes without adding substantial costs. Decorticating devices should not result in broken grains. Existing technologies already available will also be evaluated (Wilson, 2008) and modifications and improvements shall be carried out to suite the specific requirements of each grain type. Storage of grains, in smallholder farms, involves first storage of the grains into bags or bins and then keeping these bags in storage yards. Innovative methods of primary storage shall be evaluated in order to provide cheap and inexpensive options which are easy to maintain, provides ease of movement between the farms to temporary storage structures\markets thus reducing drudgery and is readily accepted in the marketing system. Innovations in order to improve the quality of the secondary storages structure shall focus on development to protect against rain, insect and rodents. Use of appropriate grain protection and preservation technologies, appropriate pest management practices shall be explored and promoted among the farmers. The above-mentioned interventions will be made after carrying out appropriate loss assessment studies.

Milestones

- Loss assessment due to storage pests and technology gap analysis in post-harvest management and storage completed for each crop and region (2012)
- Available drying technologies evaluated and compared with new innovative technologies and appropriate technology shortlisted based on cost-benefit analysis and implemented for each crop and region (2013)
- Appropriate equipment for threshing, winnowing, grading and decortication of each crop in each region identified and shortlisted, based on cost-benefit analysis of newly developed prototypes and comparison with existing technologies (2014).
- Varieties with resistance to storage pets in each crop identified, and other options for the management of storage pests evaluated (2014)
- Storage technologies for primary and secondary storage of grains evaluated and at least one technology implemented in each region for each crop and training in grain protection technologies and pest management practices imparted to farmers in the selected regions (2014)

Output 6.2. Novel and diverse dryland cereal-based products to stimulate demand for grain

Utilization of dryland cereals, in the food and feed industry, can be increased by various processing treatments, including blanching, malting, dry heating and acid treatment, that can improve their shelf-life, nutritive value, sensory qualities, etc., and make them more amenable for development of value-added food products. For example, sorghum flour is traditionally known to have reasonable level of shelf life up to 2 months, whereas pearl millet for only 5-6 days at the household level. This is a major barrier in the commercialization of sorghum and pearl millet flour and products. Recently, it was reported that moist heating of the grain followed by drying to 10-12% moisture level and decortication increases the shelf-life of pearl millet flour to about 3-4 months and sorghum to 8-10 months, though this needs to be validated for commercialization (Sehgal et al., 2003). Thus, this research output will address the effect of pre-treatments and processing on nutritive traits. Also, the effects of processing on the phytate and other micronutrient contents needs to be understood in order to develop acceptable and healthy food products from these grains.

With appropriate technological interventions, sorghum and millets can be used to produce various food products. These include, traditional products (porridges, flat breads, chips, bhakri, suhali, kichri, dalia, etc.), baked products, extruded products, health products, weaning and supplementary foods. Evidence available in the literature confirms that sorghum and millets besides being gluten-free and important sources of protein, fiber, vitamins and minerals, are also rich sources of antioxidants due to the presence of phenolic compounds (Chandrasekara and Shahidiv, 2011; Dykes and Rooney, 2006) Using food processing technology, such as fermentation, malting, extrusion, parboiling etc. nutritive products, based on sorghum and millets, with enhanced nutritional and functional quality (enhanced starch and protein digestibility), and improved shelf life have been reported. Thus, it is now possible for the food industry to develop and commercialize health products (for different consumer segments), based on sorghum and millets by use of the versatile extrusion technology and advancements in research in this area, which until now was constrained due to the non-availability of efficient processing technologies. Also, present health concerns are attributed to poor nutrition in low-income segments of the population, whereas the affluent strata of the society need to address health issues that emerge from changing lifestyles and food habits. Demand, for more healthy food products that can take care of consumer health needs due to changing life-styles, is driving the growth of the global neutraceutical industry. This has led to demand for nutritious and functional foods based on sorghum and millets (Dykes and Rooney, 2006; Taylor and Emmambux, 2008; Taylor et. al., 2006). With respect to the commercialization efforts for these value added products, entrepreneurship development linkages with the food and feed industry shall also be explored to develop a value chain for the dryland cereals crops. Increasing the market value of these dryland cereals through value addition and entrepreneurship development is essential to directly impact the lives of people, including smallholder farmers in the semiarid tropics.

Methodology

The value-added products based on sorghum and millets will be developed using suitable varieties, having desirable nutritive and processing traits, identified as part of the activities under Strategic Objective 3 (Output 3.5). Development of shelf-stable flour for commercialization shall be carried out through well designed experiments to evaluate the effect of various grain pre-treatments (blanching, dry heating, acid treatment, etc.) to inactive enzymes responsible for hydrolytic rancidity along with packaging options to further reduce oxidative rancidity. Parameters such as acid value, peroxide value and free fatty acid shall be used to establish the effectiveness of each pre-treatment in improving the shelf life. The phytate content in flour and products obtained from pre-treated grains shall also be evaluated. Formulation and process development for each product category will be undertaken using grain or flour, obtained after each pre-treatment. Appropriate processing technology (puffing, popping, parboiling, baking, roasting, frying, extrusion, spray drying, drum drying, malting, fermentation, etc.) will be explored for value-addition. The products developed will be profiled for their nutritional and sensory attributes, and wherever profiling required for bioactive components (detailed under Strategic Objective 3, Output 3.5) will be carried out. Sensory evaluation shall be carried out using both trained and untrained panels using established protocols (Merck and Company, 1963). Capacity building in the form of training and entrepreneur development programs (EDPs) for service providers (individual entrepreneurs, farmer organizations, small and medium scale entrepreneurs, food processing industries etc.) to deliver information on the innovations, marketing and technology targeting will also be an activity linked to this output, where emphasis will be on promoting women entrepreneurs.

Milestones

- Pre-treatment and packaging options optimized, using suitable varieties of sorghum and millets having desirable nutritive and processing traits, leading to shelf-stable sorghum and millets flour (2012)
- Pre-treatment and food preparation methods that maintain the nutritional value, improve digestibility and reduce anti-nutritional factors optimized and at least two value added products, targeting women and children (weaning foods etc.) from each cereal developed using these optimized methods in each region (2013).
- At least five different processing technologies evaluated resulting in the standardization of at least 2 value added food products each from sorghum and millets involving formulation optimization, nutritional and sensory profiling (2014).
- Packaging technologies and labeling protocols developed for commercialization of sorghum and pearl millet based food products (2014).
- At least two value-added food products based on sorghum and millets formulated and validated for retention of activity of their bioactive components, under optimized processing conditions (2014).

Output 6.3. Institutional innovations to improve linkages between smallholder farmers and markets

Growing demand for high-value and ready-to-cook food is opening up opportunities for smallholder dryland cereal farmers to participate in value chains, confectionary and bakery products. The derived demand for coarse cereals like sorghum, millets, maize etc. are also increasing to meet the demand from the livestock/poultry sector and other sectors like alcohol, biofuels (Aksoy, 2005; von Braun, 1995). There are however, apprehensions about the capability of smallholders to participate in the market-oriented production for high-value commodities and coarse cereals due to their scattered and small-scale production, lack of access to markets, capital, inputs, and technology and extension services. Processors need bulk quantities of raw materials of specified quality at competitive prices. Also, farmers need information on quality and prices that empowers them to bargain for a better price for their produce in the market place. Besides market information, market linkage mechanisms to enable the farmer to actually sell their produce or purchase needed inputs on time and at competitive prices are important.

Food procurement and marketing systems are thus witnessing institutional innovations like contract farming and bulk marketing through producers' associations and cooperatives, which not only provide additional marketing channels but also reduce transaction and marketing costs by eliminating a large number of middlemen (Warning and Key, 2000; World Bank, 2002; Shiferew et al., 2006). These channels also ensure that the quality requirements of end users (processors, consumers) are met as per specifications/requirements. Thus, institutional innovations in marketing improve not only access to markets, but also to quality inputs, technology, information and services. Some of the existing institutional innovations that are having potential in involving small farmers of dry-land cereals would include the following:

- *Full vertical integration:* In contrast to spot markets, full integration would prevail when there is very high degree of asset specificity, uncertainty and externality. The firm has a complete control over the processes of production, marketing, processing and distribution.
- *Cooperatives*: Cooperatives are the structures owned and managed by producers but have to work under strict functioning framework set up by the government. They improve the bargaining power of producers in situations of both high and low asset specificity and uncertainty.
- *Contracting:* This is an organizational arrangement in which a firm contracts a producer to produce a specific commodity. Through contract farming the firm exerts considerable influence over producers' decision making without owning or operating the farms. The firm may provide inputs and technology, and share production and market risks. There are a number of models to choose from depending on the requirements of the contracting parties (for details see Eton and Shepard, 2001).
- *Growers' associations:* These are informal collective bargaining groups set up and managed by farmers themselves. In Eastern Kenya, the assessment of producer marketing groups (PMG) revealed that the PMGs have the potential to simplify and shorten marketing chains, better coordinate production and marketing activities and facilitate farmer access to production inputs at fair prices (Shiferaw et al., 2006). In India, Karnataka State Farmers' Association (KSFA) that was established in 1965 by a group of 5 farmers, the membership of KSFA is now estimated to be around 10 million farmers and this association is active in linking farmers to markets at all levels – local, regional and international.
- *ICT-enabled supply chains:* Many developing countries witnessing a revolution in Information Communication Technology (ICT). Its applications in linking farmers to markets are on the rise. Okello et al. (2010a) identified alone 34 agricultural projects with ICT components in Kenya. For example the Kenya Agricultural Commodity Exchange (www.kacekenya.co.ke) is a private sector firm that makes price information available on cell phones nationwide. In India, the e-chaupal initiative of the Indian Tobacco Company provides information on market prices, agronomic practices, inputs, weather, etc. through Internet kiosks, free of charge. There are similar initiatives that are run by non-profit or research organizations as well. For example DrumNet is a project run by the research and development organization Pride Africa, which delivers market, finance, and information services to agricultural supply-chain actors in Kenya. Several such ICT-based MIS projects have also been reported in Malawi, Ghana, Uganda, Benin, and Madagascar (Okello et al., 2010b).

Methodology

Transaction cost analysis –Transaction costs can be defined as the costs of acquiring and handling the information about the quality of inputs, the relevant prices, the supplier's reputation, and so on. Specifically, Strategic Objective 6 transaction costs analyses will include: reduced cost of bargaining and negotiation; acquiring and establishing contracts; communication; monitoring and enforcing transactions/contracts; market search; information flow; costs of gathering data on price, quality of commodities and labor inputs; identifying potential buyers and settlers; actor behavior; and enforcement against defaulting and protection of rights against third party encroachment and leakages.

Market margins –The proportion of the consumer price that goes to the food-marketing firms is referred to as the marketing margin. Marketing margins may be defined in two ways: 1) as the difference between consumer retail prices and what farmers receive, and 2) as the price of marketing services provided. One of the main objectives of improving the efficiency of marketing systems is to increase farmers' share of consumer prices. Consumer price comprise of marketing components and production components. Marketing margins of all stakeholders and all marketing channels will be quantified and scope for reducing the marketing margins will be examined.

There are two methods which gives information about the various components of the costs, structure and financial situation of marketing firms: i) The Functional Method: Analyzes the different economic activities or function associated with each level of the system – e.g. farming, wholesaling, retailing, etc., and ii) The Vertical or Product Focused Method, which follows the product through the marketing process, prices, quantities, cost, etc. on each transaction.

Reducing the marketing costs of the dry land cereals through innovative institutions mentioned above will increase efficiency in the system and increase farmers share in consumer's price. It will help in increasing the overall profitability of cultivation of dry land cereals. We will assess the marketing margins by using both the functional method and the product focused methods for all existing marketing channels/activities and proposed new marketing channels and institutional innovations which will be cost effective by using the above framework for different end uses of grain like food for human consumption, feed for cattle and poultry industry and as raw material for starch and alcohol industry etc. A few pilot projects will be evaluated to test for scaling up in wider areas both in SSA and SA.

Milestones

- Existing institutional arrangements linking small holder farmers to grain and fodder markets identified and documented in each region, with special attention to women farmers/ processors (2012)
- At least two crop/region specific models for grain and fodder linking farmers to markets tested and evaluated on equity, social and efficiency parameters (2013)
- Establish at least two crop/region/commodity specific communication platform that allows the flow of information among the diverse stakeholders (2013)
- Capacity building activities regarding the functioning and up-scaling of alternative institutional innovations carried out among all stakeholders (2014)

Partners and Their Roles

Contributions from a number of traditional and entirely new partnerships are anticipated for Strategic Objective 6. Private sector companies in the dryland cereal processing sectors, as well as in the seed sector, will be key partners. In any particular value chain context it will be essential to involve key actors, such as input suppliers, extension services, development actors, credit institutes, and possibly consumer organizations. Success in creating significant new opportunities for market integration of smallholder dryland cereal farmers, specifically women, will rest on the effectiveness an array of new, non-traditional partnerships.

Relative to this strategic objective, key partners will include:

- INTSORMIL, especially on cereal grain processing;
- CIRAD, with its capacities for feed quality analysis, as well as cereal markets research experience in West Africa; and
- IRD, for basic research in pearl millet, including food processing, primarily focused on West Africa;
- Malting companies, e.g., Modelo and Cuauhtemoc Moctezuma in Mexico, Heineken in Mexico and Egypt, MOSA in Uruguay, Kenya Breweries, Nigeria Breweries, Assela Malt Factory and Ethiopian Breweries. Al-Shark in Syria);
- Industrial grain processors and their supply chain contributors: Unga flour mills, Kenya;
- Aba Malting Plant, Nigeria;
- The Hybrid Seed Parent Consortium, India;
- Local entities, such as well-established and emerging farmers' associations, to identify farmers' needs and opportunities in specific zones or regions, as well as technology testing;

- Processing industries and potential large-scale buyers, such as the World Health Programme's Purchase for Progress initiative (P4P);
- Service and input providers (local banks, extension services, agro-dealerships, and radio stations);
- Machinery developers and providers, maintenance specialists, to ensure that processing equipment functions correctly and efficiently;
- Engineering specialists in research, and in agricultural-related manufacturing and agribusinesses;
- Business incubators for sorghum and pearl millet food processing in Mali and Niger, in collaboration of INRAN, and IER, with INTSORMIL (Purdue University) and ICRISAT;
- National Agricultural Research and Extension Systems to bring in region-specific expertise and resources;
- Other CRPs, including CRP 1.1, CRP 2, CRP 7, and in particular CRP 4's agriculture, nutrition, and health platform;
- Processing and food sectors to test the laboratory-developed technologies for feasibility of application at community and commercial scales, and promotion of concerned technologies through entrepreneur development activities and test marketing; and
- Nutrition Foundations and Public Health Organizations, which can provide nutrition and health related information, facilitate nutritional studies, conduct assessments of health consequences of technology adoption, and engage in advocacy for the promotion of nutritious dryland cereals.

Appendix 5: Profiles of Initial R4D Partners

Each DRYLAND CEREALS partner provides an interdisciplinary team of scientists to address the key dryland cereal research objectives proposed and has established strong collaborative relationships with the many public and private partners where various research and development activities will be conducted. The Generation Challenge Program (GCP) is considered an Initial R4D Partner in this CRP, given the major investment it has made in characterizing genetic resources, including the dryland cereals, and in establishing integrated breeding platforms that are critical for the rapid development of improved varieties. Further details on each initial R4D partner are provided in the following.

The **International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, *www.icrisat.org*)** holds the CGIAR mandate for sorghum and millets, and operates in South Asia (SA), Eastern and Southern Africa (ESA) and West and Central Africa (WCA). These crops support the livelihoods of the poor people in the semiarid tropics encompassing 48 countries by providing food and incomes. ICRISAT has pioneered in innovating and testing a number of farmer-participatory research and delivery methods to facilitate technology development and impact. It brings to this CRP expertise in sorghum and millet breeding, biotechnology, agronomy, entomology and plant pathology, seed systems and participatory approaches for technology development and dissemination. The Centre has close ties with such Sub-Regional Organizations as ASARECA, CORAF and SADC in SSA, APAARI in South Asia, and with the national research institutes responsible for these dryland crops.

Most of ICRISAT's crop improvement research is directed at 'least-favored areas', and at an aggregate level, there is evidence from India and elsewhere compiled through independent assessments that its research is having favorable productivity and poverty impacts in these areas. Two major science-based breakthroughs attributed to crop improvement research at ICRISAT relate to pearl millet and pigeonpea. The Centre developed the first public sector-bred hybrid pearl millet, HHB 67, developed using marker-assisted selection. This new hybrid was released in India in 2006, and has spread quickly due to its superior agronomic performance and improved tolerance to terminal drought. ICRISAT researchers produced the first public sector-bred hybrid of pigeonpea as well, and since its release in 2008 it too appears to be spreading quickly.

The **International Center for Agricultural Research in the Dry Areas (ICARDA, *www.icarda.org*)** has a global mandate for the improvement of barley in developing countries. ICARDA barley improvement has three principal themes:

- Breeding for stressful environments – with a focus on adaptation to abiotic stress such as drought, cold, heat and salinity, and associated biotic stresses;
- Breeding for favorable high potential areas; and
- Breeding for cold winter areas – with a focus on winter hardiness, and other associated abiotic and biotic stresses.

ICARDA's mission is to improve the welfare of poor people and alleviate poverty through research and training in dry areas of the developing world, by increasing the production, productivity and nutritional quality of food, while preserving and enhancing the natural resource base. The Center pursues this mission through partnerships with national agricultural research systems in developing countries and with advanced research institutes in industrialized countries. The Center has developed participatory plant breeding methodologies to build on the indigenous knowledge of farmers and to make them full partners in research. ICARDA has a fully established molecular marker laboratory and the capacity to undertake field evaluations under different environmental conditions. It also maintains one of the largest global collections of barley germplasm.

The **Generation Challenge Program (GCP, *www.generationcp.org*)** was created by the CGIAR in 2003 as a time-bound 10-year program. Its mission is to use genetic diversity and advanced plant science to improve crops by adding value to breeding for drought-prone and harsh environments. This is achieved through a network of more than 200 partners (as of 2009) drawn from CGIAR Centers, academia, regional and national research programs, and capacity enhancement to assist developing world researchers to tap into a broader and richer pool of plant genetic diversity.

GCP's network advances the frontiers of knowledge and develops practical tools such as molecular markers for desirable genes, for efficient field selection in plant breeding. Through its network of partners in the CGIAR, ARIs, NARS and private sector, GCP implements programs that bring together plant scientists from different disciplines to improve crops for the ultimate benefit of resource-poor farmers. GCP works with cutting-edge plant biology research partners, and augments the efforts of the CGIAR and the broader agricultural research-for-development community. In the context of this CRP, GCP's efforts to develop an Integrated Breeding Platform and associated innovative breeding projects on various crops will be of tremendous value. This platform will comprise a one-stop-shop providing access to genetic stocks, pre-breeding materials, high throughput services for marker and trait evaluation, informatics tools, support services, capacity development and community support for conducting genomics research and integrated breeding projects.

The **Indian Council of Agricultural Research (ICAR, *www.icar.org*)** is an autonomous organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture, Government of India. Formerly known as Imperial Council of Agricultural Research, it was established on 16 July 1929 as a registered society under the Societies Registration Act, 1860 in pursuance of the report of the Royal Commission on Agriculture. The ICAR has its headquarters at New Delhi.

The Council is the apex body for coordinating, guiding and managing research and education in agriculture including horticulture, fisheries and animal sciences in the entire country. With 97 ICAR institutes and 47 agricultural universities spread across the country this is one of the largest national agricultural systems in the world.

ICAR has played a pioneering role in ushering Green Revolution and subsequent developments in agriculture in India through its research and technology development that has enabled the country to increase the production of food grains by 4 times, horticultural crops by 6 times, fish by 9 times (marine 5 times and inland 17 times), milk 6 times and eggs 27 times since 1950-51, thus making a visible impact on the national food and nutritional security. It has played a major role in promoting excellence in higher education in agriculture. It is engaged in cutting edge areas of science and technology development and its scientists are internationally acknowledged in their fields. ICAR works in partnership with a number of national and international agricultural research and development organizations:

- CGIAR centers, CABI, FAO, NACA, APAARI, UN-CAPSA, APCAEM, ISTA, ISHS, and others;
- MoUs and work plans have been established with over 30 countries for bilateral cooperation in agricultural research, training and study visits; and
- ICAR offers quality and cost-effective agricultural education to international students at under-graduate and post-graduate levels. And need-based short-term training programs in specialized areas are also offered. Special concessions for SAARC students.

The **Iranian Agricultural Research, Education and Extension Organization (AREEO, *www.areeo.ir*)** is the largest responsible body for agricultural research and education in Iran. In 1975, the Agricultural and Natural Resources Research Organization (ANRRO) was established as a central entity to formulate policies, make decisions on research priorities and coordinate the activities of the existing research institutes. In 1990, ANRRO was reorganized and merged with Agricultural Education Organization and Extension Directorate, creating a new organization naming Agricultural Research, Education and Extension Organization (AREEO) with the responsibility in the fields of Research, Education and Extension.

The two Ministries of Agriculture and Jihad Construction merged in 2001, creating the new Ministry of Jihad-e-Agriculture, and the responsibility of research institutes of the two Ministries, comprising 23 research institutes, was entrusted to AREEO.

AREEO's mission is to contribute to enhance the food security and improve well-being of the people of Iran through research and training and related activities to increase agricultural production, improve food quality, saving biodiversity and sustainably manage natural resources.

AREEO plays a pivotal role in the sustainable development of agriculture sector by generating appropriate technologies for sustainable food, feed and fiber production through its affiliated research and training institutes and centers. It also provides comprehensive information for optimum utilization of natural resources.

The first collaboration agreement between ICARDA and the Ministry of Jihad-e-Agriculture was signed in 1984 with the Agricultural Research and Education Organization (AREEO) as the focal national institution. This agreement, successively updated, was developed between ICARDA and various institutions under the umbrella of AREEO, lately renamed Agricultural Research, Education and Extension Organization (AREEO). The AREEO-ICARDA collaboration involves many of the AREEO research institutes, the three main partners in this CRP are:

- The Dryland Agricultural Research Institute (DARI) whose mission is the improvement of agricultural productivity and rural livelihood in the dry areas of Iran, including the genetic improvement of several crops including barley in dryland areas;
- The Seed and Plant Improvement Institute (SPII), responsible for the genetic improvement of various crops including barley in moisture-favorable areas, and for the management and maintenance of a genebank;
- The Agricultural Biotechnology Research Institute of Iran (ABRII) was originally established as a department of physiology in the Seed and Plant Improvement Institute in Karaj. In 1999 the Ministry of Jihad-e-Agriculture decided to create the Agricultural Biotechnology Research Institute of Iran (ABRII). In 2008 ABRII became the most important Agricultural Biotechnology Research Institute in Iran. The major goals of the Institute are: 1. Strengthening and expansion of research in the area of agricultural biotechnology and genetic engineering; 2. Promotion of national and international collaborations in the area of agricultural biotechnology and genetic engineering; 3. Solve the main agricultural problems such as biotic and abiotic stresses; and 4. Increase crop production in Iran.

The **L'institut de recherche pour le développement (IRD, *www.ird.fr*)** is a public French science and technology research institute under the joint authority of the French ministries in charge of research and overseas development. Through three main missions (research, consultancy and training), the Institute conducts scientific programs contributing to the sustainable development of Mediterranean and tropical regions, with an emphasis on the relationship between man and the environment. This work is done six major areas:

- Environmental hazards and the safety of Southern communities;
- Sustainable ecosystems management in the South;
- Southern continental and coastal water resources and their use;
- Food security in the South;
- Health in the South: epidemics, endemic and emerging diseases, healthcare systems; and
- Economic, social, identity and spatial dynamics issues in the South.

IRD research is conducted in concert with French higher education and research institutions and with partners in the South. IRD is an active participant in numerous operations supported by the European Union and takes part in many international scientific programs. Over 40% of its tenured staff is posted overseas. In September 2008, IRD moved its head office to Marseille. It maintains 30 other offices including two in France (Bondy and Montpellier), five in the French overseas territories (la Réunion, French Guiana, Martinique, New Caledonia and French Polynesia) and 23 in countries of the inter-tropical zone in Africa, the Mediterranean, Asia and Latin America.

IRD is a unique institution in the landscape of European research for development. Its task is to conduct research in the South, for the South, and with the South. Its researchers are working on issues of major global importance today: global warming, emerging diseases, biodiversity, and access to water, migration, poverty and world hunger. The teaching and training they provide empowers and enables Southern scientific communities.

IRD has been working in Southern countries for over sixty years, and has a long history of collaboration with the CGIAR. All its work – in research, consultancy and capacity building – is designed to facilitate the economic, social and cultural development of Southern countries. Through the *Agence inter-établissements de recherche pour le développement* (AIRD), IRD works to mobilize French and European universities and major research bodies to work on priority research issues for development in the South. The founding members of AIRD are CIRAD, CNRS, the *Conférence des Présidents d'Université*, Inserm, the *Institut Pasteur*, and IRD.

The **Centre de coopération internationale en recherché agronomique pour le développement (CIRAD, *www.cirad.fr/en*)** is a public industrial and commercial enterprise under the joint authority of the Ministry of Higher Education and Research and the Ministry of Foreign and European Affairs.

CIRAD works with the whole range of developing countries to generate and pass on new knowledge, support agricultural development and fuel the debate on the main global issues concerning agriculture. It is a targeted research organization, and bases its operations on development needs, from field to laboratory and from a local to a global scale.

CIRAD's activities involve the life sciences, social sciences and engineering sciences, applied to agriculture, food and rural territories. It works hand-in-hand with local people and the local environment, on complex, ever changing issues: food security, ecological intensification, emerging diseases, the future of agriculture in developing countries, etc.

The organization's operations focus on six priority lines of research. It primarily works through joint research platforms (25 worldwide and seven in the French overseas regions). CIRAD has a global network of partners and of twelve regional offices, from which it conducts joint operations with more than 90countries. Its bilateral partnerships fit in with multilateral operations of regional interest. In metropolitan France, it provides the national and global scientific communities with extensive research and training facilities, primarily in Montpellier.

CIRAD is a founding member of *Agreenium*, the national consortium for agriculture, food, animal health and the environment, and a member of the *Alliance nationale decoordination de la recherche pour l'énergie*.

The **International Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL, *www.intsormil.org*)** will be a critical partner in the Dryland Cereals CRP. It was established in 1979, and is one of nine Collaborative Research Support Programs (CRSPs) supported by USAID. INTSORMIL scientists collaborate with national research programs in East, West, and Southern Africa and in Central America. It works in 15 countries in Africa and three in Central America.

INTSORMIL's vision is to improve food security, enhance farm income and improve economic activity in the major sorghum and pearl millet producing countries in Africa and Central America. It supports international collaborative research to improve nutrition and increase incomes and focuses on enhancing the production and use of sorghum, millet and some other grains (finger millet, fonio and tef). This work has also identified new farming practices that improve yields, reduce crop losses to pests, and protect natural resources, as well as helped to develop new markets for these important grains.

INTSORMIL supports education and training, and over the past 28 years, the program has supported more than 873 foreign graduate students and 211 postdoctoral fellows and visiting scientists. Most have returned to their home countries where they continue to collaborate with INTSORMIL as scientists and research administrators. The organization's objectives are to:

- Facilitate growth of rapidly expanding markets for sorghum and pearl millet;
- Improve the food and nutritional quality of sorghum and pearl millet to enhance marketability and consumer health;
- Increase the stability and yield of sorghum and pearl millet through crop, soil and water management while maintaining or improving the natural resource base;
- Develop and disseminate information on the management of biotic stresses in an integrated system to increase grain yield and quality in the field and in storage;
- Enhance the stability and yield of sorghum and pearl millet through the use of genetic technologies;
- Enhance global sorghum and pearl millet genetic resources and the conservation of biodiversity; and

Develop effective partnerships with national and international agencies engaged in the improvement of sorghum and pearl millet production and the betterment of people dependent on these crops for their livelihoods.

APPENDIX 5: DRYLAND CEREAL CURRENT BILATERAL-FUNDED R4D PROJECTS

Title & Crops	Donor/Funding	Countries	Partners	Summary
Harnessing Opportunities for Productivity Enhancement (HOPE) of Sorghum and Millets in Sub-Saharan Africa and South Asia **Crops** Finger millet Pearl millet Sorghum	Bill & Melinda Gates Foundation US$ 18.14M (2009-2013)	Burkina Faso Eritrea Ethiopia India Kenya Mali Niger Nigeria Sudan Tanzania Uganda	ICRISAT Cornell, USA WFP/P4P AGRA/PASS IFPRI CIRAD, France NARS in target countries MAU (Marathwada Agricultural University), India MPKV (Mahatma Phule Krishi Vidyapeeth), India Sokoine University of Agriculture, Tanzania Maseno University, Kenya) Hawassa University, Ethiopia Haramava University, Ethiopia Unga Mills, Kenya Africa Harvest, Kenya	Focusing in carefully-selected target areas that provide a large opportunity to alleviate food insecurity and poverty in West/Central Africa, Eastern/Southern Africa and South Asia, the HOPE Project discovers, develops and delivers improved technologies for producing three major dryland cereal crops: sorghum, pearl millet, and finger millet. Organizations providing seed, fertilizer, credit, and know-how are interlinked with producers, buyers, and marketers so that increased production is enabled by essential inputs, and driven by market demand. Synergies between improved crop varieties and fertilizer, farmer participation, and gender equity receive particular emphasis. In its first 4 years, the project will increase farmer yields by 30% or more, benefiting 110,000 households in Sub-Saharan Africa and 90,000 in South Asia through increased food security and incomes. Within ten years the project will benefit 1.1 million households in Sub-Saharan Africa and 1.0 million in South Asia.
PROMISO: Strengthening West African farmers' and Researchers' Capacity to Jointly Adapt New Pearl Millet and Sorghum Varieties and Crop Production Innovations **Crops** Pearl millet Sorghum	EC US$ 5.75M	Benin Burkina Faso Ghana Mali Niger Senegal	ICRISAT NARS in target countries	The overall objective of the PROMISO project is to strengthen the capacity of partners to produce higher and more stable grain yields of sorghum and pearl millet for West Africa. The project contributes to this objective by (1) enhancing farmers' and researchers' skills and capacities in participatory testing and scaling up of crop pearl millet and sorghum crop intensification technologies; (2) increasing farmer's varietal options for sorghum and pearl millet; (3) developing training resources in a range of media forms for continued and large scale farmer, researcher, and development community capacity building; (4) enhancing researchers' and development partners' capacities to monitor outcomes and impacts; (5) strengthening regional coordination and monitoring capacity with ECOWAS – CORAF; and (6) enhancing visibility of EU and CORAF and awareness of the vital role of sorghum and pearl millet production systems for food security, nutrition, and income.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Establishing a Molecular Breeding Program Based on the Aluminum Tolerance Gene, *Alt*$_{SB}$, and the P Efficiency QTL, *Pup-1*, for Increasing Sorghum Production in Sub-Saharan Africa **Crops** Sorghum	Generation Challenge Program US$ 0.545M (2010-2013)	Brazil Kenya Mali Niger	ICRISAT EMBRAPA, Brazil Institut National de Recherches Agronomiques du Niger (INRAN), Niger Moi University, Kenya Cornell, USA USDA/ARS, USA	This project will implement a molecular breeding program targeting Mali, Niger and Kenya using random mating ms3 populations (RMPs) for the eventual development of improved varieties and breeding materials with Al tolerance and improved performance under low P stress. These two target traits largely underlie adaptation to acid soil and low phosphorus conditions. Also included is a capacity building component to be held at Moi University for training scientists from Mali, Niger, and Kenya and nearby countries to establish the necessary skills for sustainable molecular breeding activities. The ultimate goal is to develop the capacity and necessary tools in African institutions for stacking desirable genes in the development of elite multiple trait cultivars and to develop breeding materials that show superior performance in soils where Al toxicity and low P availability can cause serious reductions in productivity.
Enhancing Sorghum Grain Yield and Quality for the Sudano-Sahelian Zone of West Africa using the Backcross Nested Association Mapping (BCNAM) Approach **Crops** Sorghum	Generation Challenge Program US$ 0.800M (2010-2013)	Mali	Institut d'Economie Rurale (IER), Mali CIRAD, France ICRISAT	This project will enhance the capacity of national and international breeding programs to using sorghum germplasm diversity and advanced molecular tools. The project will result in the development of modified backcross populations that will be of long-term value in relating sorghum traits to their corresponding genes. The planned population structure will facilitate the QTL mapping of range of traits conditioning productivity, adaptation, and preferred grain quality traits. Forty to fifty populations of 100 lines each will be developed from backcrosses carried out with 3 recurrent parents that represent the target ideotypes to be improved. The capacity of National breeding programs will be strengthened by creating a regional data management unit within the IER (Mali), which will support scientists in the effective application and use of molecular data for improved effectiveness of sorghum breeding activities.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Improving Phosphorus Efficiency in Sorghum by the Identification and Validation of Sorghum Homologs for *Pup1*, a Major QTL Underlying Phosphorus Uptake in Rice **Crops** Sorghum	Generation Challenge Program US$ 0.805M (2010-2013)	Mali Niger	Cornell, USA Institut National de Recherches Agronomiques du Niger (INRAN), Niger Moi University, Kenya ICRISAT IRRI EMBRAPA, Brazil JIRCAS, Japan USDA/ARS, USA	*Pup1* is a major QTL located on rice chromosome 12 that underlies phosphorus efficiency and has the potential to increase P acquisition efficiency in other cereals. Research findings from a long term collaboration between IRRI and JIRCAS has resulted in the fine mapping of the *Pup1* locus to a ~150 Kb region on chr 12, and 2-4 high quality *Pup1* candidate genes have been identified. Taking advantage of the complete sequence of the sorghum genome, the project will establish a framework based on comparative genomics to identify sorghum *Pup1* homologs and will validate their role as *bona fide* genes underlying tolerance to P deficiency. Positive associations will be validated by bi-parental mapping and analysis of near-isogenic lines. We will also study a possible synergistic role of Al tolerance gene Alt_{SB} in increasing P uptake into sorghum roots. The genetic framework that will be developed for this research will also be useful for identifying other novel QTL related to P efficiency, which can then be deployed into a molecular breeding platform.
Improve sorghum productivity in semi-arid environments of Mali through integrated MARS **Crops** Sorghum	Generation Challenge Program US$ 0.68M (2008-2012)	Mali	IER, Mali Syngenta CIRAD	The present project illustrates through a private-public partnership, the value of the MARS approach for sorghum breeding in Mali. It will combine recent approaches on sorghum breeding that have been developed at IER and methodologies for marker assisted recurrent selection (MARS) that have proven to provide significant improvement of breeding efficiency for complex traits, especially in the case of maize. Two populations dedicated to two different environments of sorghum crop in Mali will be developed from the cross of local well-characterized advanced breeding cultivars exhibiting complementary traits for the target environment. A multi-location evaluation of the progenies together with genotyping will provide accurate QTL detection for a number of important traits. This QTL information will be used in several consecutive cycles of recurrent selection aiming at pyramiding favorable alleles for selected QTLs. All along the process, material will be released to develop new varieties

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Improving Post-rainy Sorghum Varieties to Meet the Growing Grain and Fodder Demand in India **Crops** Sorghum	ACIAR US$ 1.13M (2008-2012)	India	ICRISAT Directorate of Sorghum Research, India Queensland Department of Primary Industries & Fisheries, Australia University of Queensland, Australia ILRI	Post-rainy season sorghum, although grown on residual soil moisture and commonly exposed to terminal drought stress, has an excellent market potential, for its high quality of grain and stover. Genetically improving the efficiency of using stored soil moisture by maximizing post-anthesis water use and water use efficiency (WUE) to enhance grain filling, is a prime target to maximize grain/stover production and quality. A step towards this goal has recently been obtained in early generation marker-assisted selection (MAS) products having six different stay-green quantitative trait loci (QTL). A major objective is to develop single- and multiple-QTLs stay-green introgression isolines, and assess the contributions of each of these QTLs to grain/fodder productivity and grain/fodder quality under both drought-stressed and non-stressed conditions. A second objective is to identify, via crop simulation modeling, the traits contributing to a better use of the soil profile moisture, and assess their putative links to individual stay-green QTLs and potential impact on overall productivity of mixed crop livestock systems of drought-prone areas of India.
Tackling Abiotic Production Constraints in Pearl Millet and Sorghum-based Agricultural Systems of the West African Sahel **Crops** Pearl millet Sorghum	BMZ/GIZ US$ 1.63M (2010-2013)	Burkina Faso Mali Niger Senegal	ICRISAT Institut National de l'Environnement et Recherche Agricole (INERA), Burkina Faso Institut d'Economie Rurale (IER), Mali Institut National de Recherches Agronomiques du Niger (INRAN), Niger Institut Sénégalais de Recherche Agricole (ISRA), Sénégal University of Hohenheim, Stuttgart, Germany University of Kassel, Witzenhausen, Germany	Using an integrated genetic and natural resource management (IGNRM) approach, this project aims at enhancing adaptation of pearl millet [*Pennisetum glaucum* (L.) R. Br.] and sorghum [*Sorghum bicolor* (L.) Moench] to low-phosphorus (P) soils and water stress in the Sahelian zone of West Africa (WA). A combination of physiological experiments, classical and marker-assisted breeding research, and agronomic studies is used to tackle the combined effects of low soil P and droughts on pearl millet and sorghum growth in West Africa's smallholder cereal production systems. In a step-wise approach the studies will unravel available genetic diversity for low-P tolerance and relative importance of low soil P and water stress, and their interaction, for cereal productivity in the Sahel. New crop management techniques beyond fertilizer micro-dosing will be developed and tested, such as seed coating with P, promotion of symbiosis with vesicular-arbuscular mycorrhiza (VAM) and on-farm processing of rock phosphate (cropolites), to help enhancing productivity under Sahelian abiotic stress conditions. A strong focus on farmer experimentation with adapted cereal cultivars and new crop management options will validate these techniques and contribute to early adoption and project impact.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Assessing and Refining the Concept of Dynamic Genepool Management and Simultaneous Farmer Participatory Population Improvement in Pearl Millet & Sorghum **Crops** Pearl millet Sorghum	McKnight Foundation US$ 0.43M (2010-2014)	Burkina Faso Mali Niger	ICRISAT Institut National d'Etudes et de Recherches Agronomiques (INERA), Burkina Faso AMSP, Burkina Faso UGCPA, Burkina Faso Institut d'Economie Rurale (IER), Mali Association des Organisations Professionnelles Paysannes (AOPP), Mali Union Locale des Producteurs de Cereales (ULPC), Mali ASEDES, Mali Fuma Gaskiya, Niger Mooriben, Niger	This project will validate and finalize new sorghum and pearl millet experimental cultivars developed in the previous phase, and determine the selection progress realized for various traits and selection methods, so as to refine future breeding strategies in the three countries. In pearl millet, the participatory population improvement will be further pursued and extended to the Dioula and Mande sites in the Sudanian zone of Mali. Furthermore, we seek to enhance progress of pearl millet breeding for resistance to the parasitic weed *Striga hermonthica* through development of a marker-assisted recurrent selection (MARS) scheme, which will be integrated with the participatory research. Finally, we propose to study whether the approach and methods used in the first phase contributed to genetic diversification of the germplasm grown in farmers' fields and therefore to *in-situ* conservation of genetic resources, for both sorghum and pearl millet.
Sustaining Farmer-Managed Seed Initiatives for Sorghum and Pearl Millet in Mali, Niger, and Burkina Faso **Crops** Pearl millet Sorghum	McKnight Foundation US$ 0.57M (2010-2014)	Burkina Faso Mali Niger	ICRISAT Minim Sông Pânga, Burkina Faso Union de Groupement pour la commercialisation des Produits Agricole, Boucle du Mouhoun (UGCPA/BM), Burkina Faso Union Locale des Producteurs de Cereales (ULPC), Mali Association des Organisations Professionnelles Paysannes (AOPP), Mali Fuma Gaskya , Niger Mooriben, Niger Institut d'Economie Rural (IER), Mali Institute National de l'Environmental et des Recheres Agricoles (INERA), Burkina Faso Institut National de la Recherche Agronomique du Niger (INRAN), Niger	This project will strengthen the capacities of local seed initiatives by building on previous efforts such as improved seed business management skills; by pursuing new approaches to systematically involve women in all seed activities; by working with a range of communication tools; and, by strengthening farmer organization's capabilities to use the results of farmer managed trials. The project will also develop method(s) to evaluate varieties for new traits of particular importance to farmers, such as food yield from a given quantity of grain. This project will initiate specific studies to improve our understanding of changes in farmer seed systems due to project activities.
Diversification of Pearl Millet Hybrid Parents for Increased Stable Production **Crops** Pearl millet	Pearl Millet Hybrid Parents Research Consortium (India) US$ 0.41M (2009-2013)	India	ICRISAT	

Title & Crops	Donor/Funding	Countries	Partners	Summary
Diversification of Sorghum Hybrid Parents for Increased Stable Production **Crops** Sorghum	Sorghum Hybrid Parents Research Consortium (India) US$ 0.41M (2009-2013)	India	ICRISAT	
Integrating Genomics and Mapping Approaches to Improve Pearl Millet Productivity in Drought Prone Regions of Africa and Asia **Crops** Pearl millet	BBSRC (UK) US$ 0.23M (2008-2012)	India	ICRISAT	
Transfer of Sorghum and Millet Production, Processing and Marketing Technologies Program in Mali (INTSORMIL) **Crops** Pearl millet Sorghum	USAID Mission/Mali US$ 5.25M (2007-2012)	Mali	IER AMEDD CONFIGES CRRA DRA IICEM SAAG 2000	The project will promote profitable markets for sorghum and pearl millet by working with agencies that identify and expand markets, assess economics, and facilitate evolution of a production-supply chain and expanding markets to deliver quality grain to end-users. Targeted basic and applied research, education/short term training and technology transfer will promote adoption and economic impact. Components include training, production, marketing and food processing.
INTSORMIL **Crops** Sorghum	USAID FTF/W	Costa Rica El Salvador Guatemala Haiti Honduras Nicaragua Panama	INTA CENTA ICTA CHIBAS BIOENERGY DICTA INTA IDIAP	Sorghum is the second major crop grown in Central America where it is grown as a source of forage, silage, and as a grain for livestock and humans. *BMR* (Brown midrib) sorghum which has a high nutritional value to dairy cows is being transferred to small holder farmers in Central America and Haiti via a rapid (3 year) technology transfer process.

Title & Crops	Donor/Funding	Countries	Partners	Summary
International Sorghum and Millet Collaborative Research Support Program (INTSORMIL) **Crops** Finger millet Pearl millet Sorghum	USAID/Washington US$ 12.90M (2006-2011)	Burkina Faso El Salvador Ethiopia Ghana Kenya Mali Nicaragua Niger Nigeria Senegal South Africa Botswana Tanzania Uganda Zambia Mozambique	Kansas State Univ. Ohio State Univ. Purdue Univ. Texas A&M Univ. West Texas A&M Univ. USDA/ARS Dupont/USA CENTA/El Salvador CNIA/INTA/Nicaragua AMPROSOR/Nicaragua UNA/Nicaragua CNIAB/Nicaragua ITA/Senegal ISRA/Senegal EISMV/Senegal IER/Mali CRRA/Mali INRAB/Burkina Faso CREAF/Burkina Faso INERA/Burkina Faso IRSAT/Burkina Faso INRAN/Niger CERRA/Niger Lake Chad Research Station/Nigeria Univ. Maiduguri/Nigeria SARI/Ghana NARO/Uganda EIAR/Ethiopia Alemaya Univ./Ethiopia Axum Univ./Ethiopia KARI/Kenya Tanzania/Hombolo Res. Station Dept Crop Res./Tanzania Sokoine Univ./Tanzania IIAM/Mozambique Med. Res. Council/So. Afr Univ. of Free State/So. Afr. Univ. of Pretoria/So. Afr. College of Agr./Botswana Zari/Zambia UNZA/Zambia	The overall vision for the Sorghum, Millet, and Other Grains CRSP is to improve food security, enhance farm income, and improve economic activity in the major sorghum-and pearl millet-producing countries of Africa and Central America. Significant research advances have been made with resultant technologies starting to be exploited in pilot programs in several regions. There are increasing opportunities for farmers producing the staple food crops to participate in new markets and increase their incomes. In West Africa, these opportunities include linking farmers using improved "tan-plant, white-grain cultivars combined with use of improved agronomic practices, with end-users producing products including processed pearl millet as couscous and other food uses, and sorghum for poultry feed. In Eastern Africa, farmers growing *Striga* resistant sorghum cultivars as part of an integrated crop management strategy have increased sustainable grain yields. Tan-plant, white grain cultivars are being used to produce an increasingly popular lager beer in East and Southern Africa, and for bread and snack foods in Central America.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Rapid generation advancement of Korean barley lines through the Double Haploid Technology **Crops** Barley	Rural Development Administration (S Korea) US$ 0.02M (2007-2011)	S Korea	ICARDA Rural Development Administration	This project will produce Korean barley lines with good agronomical performances and high end use quality characteristics using well-developed doubled haploid production systems from ICARDA.
Fair Access and Benefit Sharing of Genetic Resources: National Policy Development **Crops** Barley	IDRC US$ 0.32M (2007-2011)	Jordan	ICARDA NCARE (Jordan) IDRC (head office)	The overall objective is to develop new policies and laws that recognize and support the key contributions of rural people to the processes of sustainable genetic resources management and improvement, dynamic biodiversity conservation, and rural innovation. Specific objectives include: raising awareness among and empower farmers regarding their voice and rights in policies and laws related to genetic resources; getting participatory plant breeding products recognized legally and properly valued economically; and changing policies and laws concerning variety release and seed production in support of participatory plant breeding practices and its products.
Identification and utilization of durable resistance to diseases in barley in Latin America **Crops** Barley	FONTAGRO US$ 0.14M (20072011)	Uruguay	ICARDA Uruguay Peru	This project is aimed at contributing to the development of productive strategies that increase water productivity in order to offset the effects of climate change in South America.
Collaboration in the development of barley germplasm and screening for disease resistance and end-use quality **Crops** Barley	Alberta Agricultural and Rural Development (AARD) US$ 0.20M (2008-2013)	Canada	ICARDA AARD (Canada)	This project is a collaboration with the Agriculture, Food and Rural Development Agency (AARD) that will exchange germplasm, screen germplasm for diseases, and evaluate genetic lines of barley that have potential for genetics and commercial applications.
Integrated improvement of cereal-based cropping systems in rainfed and irrigated areas of Great Jamahirya **Crops** Barley	ARC – Libya US$ 8.70M (2009-2013) SUSPENDED	Libya	ICARDA ARC-Libya	The objectives of this program will be to enhance Libya's national program capacity and relations with regional and international centers and enable the national program to benefit through ICARDA from experiences with other CGIAR Centers in the area of cereal-based cropping systems.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Development of Improved Varieties of Malting Barley **Crops** Barley	Impulsora Agricola, S.A. de C.V. (IASA) US$ 0.90M (2009-2012)	Mexico	ICARDA IASA	This project consists of a quality and agronomic assessment in Mexico of existing advanced lines maintained by ICARDA. ICARDA will introduce and assess in Mexico different types of barleys from Peru, Ecuador, Canada, and the United States, will identify and select the segregating populations adapted to the Mexican environment, and will develop at least 1,200 experimental lines per year to be assessed for agronomic and pathological evaluation in Mexico.
Barley Improvement for High Yielding Quality Malt, Food and Feed for Various Agro-ecologies **Crops** Barley	ICAR US$ 0.05M Annually	India	DWR ICARDA	This project will develop high yielding barley varieties with superior malting quality for plains of northern India. It will also develop high yielding barley cultivars for rainfed condition with drought and salinity tolerance in plains and drought & cold tolerance in hills.
Strategies for Organic and Low-input Integrated Breeding and Management (SOLIBAM) **Crops** Barley	EU US$ 0.46M (2010-2014)	Ethiopia Mali	ICARDA EU Partners University of Mekelle, Ethiopia CNOP, Mali	This is a large consortium of European partners (France, Switzerland, Italy, Hungary, Denmark, Spain, Portugal) addressing a wide range of crops. ICARDA is contributing to barley in Ethiopia and participatory breeding approaches in Ethiopia and Mali (Coordination Nationale des Organisations Paysannes du Mali, CNOP)
Improving the Food Security and Climate Change Adaptability of Livestock Producers using the Rainfed Barley-based System in Iraq and Jordan **Crops** Barley	IFAD US$ 1.50M (2011-2014)	Jordan Iraq	ICARDA NCARE MoA-Iraq	The project aims to increase productivity and climate change resilience among farming communities in targeted areas of Iraq and Jordan. The project's targeted areas are those where rainfall is equal to or less than 350mm and barley is the main source of feed for small ruminant livestock production systems The main target group is resource-poor farmers and livestock producers in rainfed barley-based system whose livelihoods are dependent on the system and who have limited income or skills diversification and limited access to pertinent information and technological developments. In addition, emphasis is placed on targeting the next generation of farmers to ensure intergenerational continuity and knowledge and skills transfer.

Title & Crops	Donor/Funding	Countries	Partners	Summary
ARCAD **Crops** Pearl Millet Sorghum	Agropolis Foundation US$ 4.29M (2009-2013)	Benin Burkina Faso France Guinea Kenya Mali Morocco	CIRAD IRD Montpellier SupAgro INRA UM2 : Université de Montpellier 2 FOFIFA IRAG Institut Agronomique et Vétérinaire Hassan II IER INERA INRAB KARI	The ARCAD scientific project aims to contribute to a better conservation and use of Mediterranean and tropical crop genetic resources. It is focused on the study of the relationship between crop diversity and the processes of domestication and adaptation to the agricultural environment. Understanding how genes and genomes have been shaped by history, environment and societies is a key factor to enhance the quality and sustainability of germplasm conservation and use. The scientific project is set on a limited number of priorities: - The study of the history and patterns of crop domestication and adaptation - The analysis of the key parameters underpinning adaptation, at various time scales, through studies of evolutionary genomics and population genetics. The ARCAD scientific project includes several research sub-projects addressing these priorities as well as technological, methodological and capacity building components which aim at supporting these sub-projects, at strengthening the overall consistency and enhancing the attractiveness of the entire ARCAD project.

Title & Crops	Donor/Funding	Countries	Partners	Summary
AFTER project: African Food Tradition Revisited by Research **Crops** Pearl millet Sorghum	EU FP7 US$ 5.55M (2010-2014)	France Benin South Africa Egypt Madagascar Senegal Cameroon Ghana UK Italy Portugal	Cirad France UAC : University of Abomey Calavi / Faculty of Agronomy - Benin CSIR : Council for Scientific and Industrial Research - South Africa FAAU : Faculty of Agriculture, Alexandria University - Egypt ACTIA : Association de Coordination Technique pour l'Industrie Agro-alimentaire - France UT : Antananarivo University - Madagascar UCAD : Ecole Supérieure Polytechnique / Cheikh Anta Diop University of Dakar - Senegal ENSAI : National School of Agro-Industrial Sciences - Cameroon ESB : Escola Superior de Biotecnologia - Portugal NRI : Natural Resources Institute - United Kingdom AAFEX : Association AFrique agro EXport - Senegal SPES : Spread European Safety - Italy INRA : National Institute for Agricultural Research - France FRI : Food Research Institute - Ghana Racines - France NRC : National Research Centre - Egypt	The overall objective of AFTER is to improve traditional African products in the light of combined and/or new technologies for mutual benefits for the consumers, the companies and the producers of Africa and Europe. The project has four general objectives valid for ten traditional products from Africa: - To reach comprehensive scientific knowledge of the existing know-how on technologies, processes and products. - To propose improved traditional processes by a reengineering of the unit operations with the aim of improving the safety and nutritional quality while keeping or improving the organoleptic characteristics of traditional products. - To reach objective criteria of acceptability of the traditional products by the consumers and to ensure that the products can effectively access the EU markets in view of regulatory and ethical issues while also protecting the intellectual rights of the people in Africa. - To present the results into ready-to-use information for food companies including SMEs via guidelines on quality management, food law and regulation and consumer protection and to transfer the results to the stakeholders from Africa and from the EU.
SWEETFUEL **Crops** Sorghum	EU FP7 US$ 7.32M (2009-2014)	France India Mexico Germany South Africa Italy Brazil Italy	CIRAD ICRISAT EMBRAPA Ifeu - Institut Fuer Energie- Und Umweltforschung Heidelberg Gmbh Universidad Autonoma De Nuevo Leon Wirtschaft Und Infrastruktur Gmbh & Co Planungs Kws Saat Ag Agricultural Research Council (ARC) Universita Cattolica Del Sacro Cuore Alma Mater Studiorum-Universita Di Bologna	The main objective of SWEETFUEL is to optimize bioethanol production from sorghum in temperate, semi-arid and sub-tropical regions by genetic enhancement and improvement of agricultural practices.

Title & Crops	Donor/Funding	Countries	Partners	Summary
Sustainable management of agricultural biodiversity in Mali **Crops** Sorghum	FFEM US$ 1.43M (2009-2013)	Mali	CIRAD IRD ICRISAT AFD UNSCPC IER AOPP	The project aims at developing sustainable management of agricultural biodiversity. In a context of socio-economic and climate changes, it will strengthen the durability of production systems. Among others, the projects objectives are to promote and develop participatory breeding and biodiversity management for sorghum and pearl millet at the level of farmer organizations, and to address IP issues of farmer access to genetic resources as well as benefits sharing of participatory breeding products.