DRYLAND CEREALS
A global alliance for improving food sufficiency, 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

1 May 2011

In collaboration with
Generation Challenge Program (GCP)
Indian Council of Agricultural Research (ICAR)
Institut de Recherche pour le Développement (IRD)
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)
Sorghum, Millet and Other Grains Cooperative 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
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 that of India, France, 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 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: 1.1 (“Integrated agricultural production systems for the poor and vulnerable in dry areas”); 2 (“Policies, institutions, and markets to strengthen assets agricultural incomes for the poor”); 3.1 (WHEAT: Global alliance for improving food security and livelihoods of resource poor in the developing world); 3.2 (MAIZE: Global alliance for improving food security and livelihoods of resource poor in the developing world); 3.3 (GRISP: a global rice science partnership); 3.5 (“Grain Legume Value Alliance”); 3.7 (“Sustainable staple food productivity increase for global food security: livestock and fish”); 4 (“Agriculture for improved health and nutrition”); 5 (“Durable solutions for water scarcity and land and ecosystem degradation”); and 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 largely due to the hard work, commitment and dedication of the line 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 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. 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 this one. Helpful reviews of the September 2010 submission guided fresh thinking and the redevelopment of DRYLAND CEREALS, and those inputs have been fully acknowledged in this version of the proposal dated May 1, 2011 and submitted to the CGIAR Consortium Board.
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<tr>
<td>IPM</td>
<td>Integrated Pest Management</td>
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<td>IRD</td>
<td>Institut de Recherche et Développement, France</td>
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<td>ISF</td>
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<td>International Society for Horticultural Science</td>
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<td>ISTA</td>
<td>International Seed Testing Association</td>
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<td>ITPGRFA</td>
<td>International Treaty on Plant Genetic Resources for Food and Agriculture</td>
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<td>KM</td>
<td>Knowledge Management</td>
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<td>LDL</td>
<td>Low-Density Lipoprotein</td>
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<td>LIFDCs</td>
<td>Low Income Food Deficit Countries</td>
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<td>M&amp;E</td>
<td>Monitoring and Evaluation</td>
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<td>MET</td>
<td>Multi-Environment Trials</td>
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<td>NACA</td>
<td>Network of Aquaculture Centers in Asia-Pacific</td>
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<td>NARES</td>
<td>National Agricultural Research and Extension Systems</td>
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<td>OECD</td>
<td>Organization for Economic Cooperation and Development</td>
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<td>OPVs</td>
<td>Open-Pollinated Varieties</td>
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<td>P4P</td>
<td>Purchase for Progress, World Food Program</td>
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<td>PRA</td>
<td>Participatory Rural Appraisal</td>
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<td>Participatory Research and Gender Analysis</td>
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<td>PVS</td>
<td>Participatory varietal selection</td>
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<td>QTL</td>
<td>Quantitative Trait Loci</td>
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<td>R4D</td>
<td>Research-for-Development</td>
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<td>REDD</td>
<td>Reduced Emissions for Deforestation and Forest Degradation</td>
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<td>ReSAKKS</td>
<td>Regional Strategic Analysis and Knowledge Support System</td>
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<td>Regional Coordination Committee</td>
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<td>SRF</td>
<td>Strategic and Results Framework</td>
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<td>Sub-Saharan Africa</td>
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<td>TPE</td>
<td>Target Populations of Environments</td>
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<td>United Nations</td>
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<td>UN-CAPSA</td>
<td>Centre for Alleviation of Poverty through Sustainable Agriculture</td>
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<td>UNDP</td>
<td>United Nations Development Program</td>
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<td>UPOV</td>
<td>International Union for the Protection of New Varieties of Plants</td>
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<td>USAID</td>
<td>United States Agency for International Development</td>
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<td>CWANA</td>
<td>Central and West Asia and North Africa</td>
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<td>WCA</td>
<td>West and Central Africa</td>
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<td>XRF</td>
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EXECUTIVE SUMMARY

The CGIAR has long been one of the few organizations that has paid attention to the dryland agro-ecological zones found in many developing countries around the world. That attention notwithstanding, at least half or more of the more than 1 billion people living in these areas struggle to survive on only US$ 1/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 specifically on improving the productivity, profitability, and nutritional content of the major cereal crops commonly grown there – barley, finger millet, pearl millet and sorghum. DRYLAND CEREALS partners believe that far stronger efforts are urgently needed to address key challenges afflicting the drylands and their agricultural production systems, which are vital to creating a better tomorrow for hundreds of millions of the most vulnerable people in the world. In many places, population pressure and the need for agricultural intensification have brought key dryland cereal production systems under increasing stress. Poverty, food insecurity and environmental degradation in the drylands are clearly exacerbating the situation.

Taken together, the farm gate value of barley, finger millet, pearl millet and sorghum, produced in Low Income Food Deficit Countries (LIFDCs) is equivalent to that of maize (Table 3). Given their substantial economic value and their importance as a mainstay for the hundreds of millions living in our target areas, relatively limited resources have been and continue to be allocated to dryland cereals.

The demand for these crops is driven by a common set of factors. For example, about 50% of the demand for dryland cereals is related to sustaining livestock (feed and fodder) in integrated crop/livestock systems, while at least 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, ethanol and dairy), which is providing increasing amounts of cash income to smallholder farmers.

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 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 much-needed critical mass in research aimed at achieving development impacts. Moreover, there are common researchable issues associated with these crops including, but far from limited to:

- Determining the potential for increasing total biomass production and quality;
- 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 market access, seed delivery systems, production and market-related policies; and
- The importance of improving post-harvest processing for better shelf life and nutritional value.

DRYLAND CEREALS R4D efforts and outputs will be 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 strong genetic tolerance for drought, high temperatures and soil salinity, as well as strong tolerance for or resistance to pests and diseases. These crops have higher nutritional value in terms of important micronutrients (zinc, iron, calcium), 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 critically 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 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. Specific major innovations include the following (for details, see Program Innovations Section):

- 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 and the application of marker-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**

The overall vision of success for DRYLAND CEREALS is three-fold: 1) significant and sustainable production increases, quality improvement, and greater availability of these cereals for 15 million smallholder farmers in Asia and Africa; 2) measurably better livelihoods for these same households through improved productivity, more resilient and productive dryland crop/livestock systems, and better access to markets; and 3) notably enhanced nutritional value of these cereals. DRYLAND CEREALS will plan for and implement a gender-focused R4D approach in the drylands, with particular emphasis given to food processing and value-adding business opportunities for women.

Specifically, DRYLAND CEREALS will increase the stability of production, productivity (yield per unit area), and production (total availability) of cereals grown in dryland environments. During the next 6 years, the Program will generate at least 150 new varieties that have the traits preferred by farmers and consumers in target countries, and these varieties will be capable of ensuring production gains of at least 1% per year. The formal and informal seed sectors (public and private) will be mobilized to produce and disseminate quality seed of improved varieties to targeted smallholder farmers, with particular attention paid to those who usually face the greatest difficulties in accessing seed and other inputs. The value added from DRYLAND CEREALS that will accrue to smallholder farmers in targeted areas is expected to reach nearly US$ 2 billion by 2020.

**A FOCUS ON GENDER**

Gender mainstreaming 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 in our 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 opportunities for women.

**STRATEGIC OBJECTIVES AND OUTPUTS**

DRYLAND CEREALS is focused primarily on the core competencies of crop improvement, cropping systems and post-harvest technologies, with significant efforts in production systems and price, trade and policy areas (see Figure 1). Beyond these traditional core competencies, DRYLAND CEREALS also brings expertise and focus to new areas identified in the Strategic Results Framework (SRF) such as climate change adaptation/mitigation and nutrition and health.

DRYLAND CEREALS is structured around three key Strategic Objectives:

- **SO 1:** Increasing and sustaining the production of dryland cereals by smallholder farmers in Africa and Asia to achieve food sufficiency
- **SO 2:** Contributing to economic growth by improving the profitability of dryland cereals production and increasing marketing options
- **SO 3:** Optimizing nutritional value of dryland cereals for better health

Each of these Strategic Objectives is designed from a value-chain and system perspective to address one or more of the CGIAR System Level Outcomes, as well as relevant key challenges and opportunities. Within each Strategic Objective, specific activities and outputs have been defined (see Activities and Outputs). These will lead to outcomes at the immediate client level, and then to outcomes at the beneficiary level, i.e., smallholder farmers (see Impact Pathway).

While all three Strategic Objectives are important in each target region, differing emphasis will be given within each region 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 the 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 East and southern Africa regions are more transitional with a broader mix of farmers and opportunities, thus requiring a more balanced emphasis. Nutritional improvement will be emphasized more or less equally across all regions.

**CAPACITY STRENGTHENING**

Capacity strengthening will be integrated throughout DRYLAND CEREALS and most R4D activities will contain capacity strengthening-related outputs. 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 grass-roots 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 to achieve desired outcomes in order to ultimately have impacts on 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. 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 area, 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 suffer from hunger and malnutrition, especially in the months leading up to harvest. Women and children, who are less empowered within households, often suffer the most. By improving the production, productivity and nutritional content of dryland cereals (the latter building on existing HarvestPlus research efforts and partnerships), smallholder farmers who grow them will automatically capture much-needed benefits.

While DRYLAND CEREALS contributes mainly to the first three System Level Outcomes, our objective to improve abiotic stress tolerance will help ensure that further environmental degradation of the drylands is minimized. In addition, by improving the productivity and profitability of dryland cereals, farmers will be less likely to switch to other cereals, such as maize or rice, that are less efficient in the use of natural resources. Further reduction of environmental degradation will also be achieved through research aimed at optimizing dryland cereal/legume cropping systems.

**PARTNERS INVOLVED**

ICRISAT is the “Lead Center” for DRYLAND CEREALS, and ICARDA is its principal 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), Indian Council of Agricultural Research (ICAR), 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 Cooperative 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 Partners and Table 5).

**INTERACTIONS WITH OTHER CRPs**

DRYLAND CEREALS will link with – and leverage resources, information, partnerships and technologies from – a number of other CRPs (see Table 6). Specifically, DRYLAND CEREALS will:

- Work with CRP 1.1 (Dryland Systems) to better fit optimal dryland cereal production technologies in smallholder 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 aims to increase the average productivity of its target crops by at least 10% by 2020, which will result in an increase in production of about 7 million tons in total production by 2020. At current average prices, this additional annual production will be worth about US$ 2 billion at the farm gate, and will have resulted from an average annual investment in R4D activities of US$ 30 million per year.
VISION AND OBJECTIVES

The CGIAR has a long history of being one of the few international agricultural research organizations that has given significant attention to the dryland agro-ecological zones found in many developing countries around the world. That attention notwithstanding, half or more of the approximately 1.5 billion people living in these areas (especially those in Sub-Saharan Africa) struggle to survive on only US$ 1.25/day or less, usually from smallholder subsistence agriculture. Both Africa and Asia contain deep pockets of poverty that are closely aligned to where the drylands are, though because of its population density the number of absolute poor living in Asia’s dryland areas 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, clearly much more needs to be accomplished.

The DRYLAND CEREALS CRP is squarely focused on improving the productivity of the major cereal crops that are commonly grown in the dry areas of Asia and Africa – barley, finger millet, pearl millet and sorghum. This effort will rest on true partnership and strengthened capacities in the target countries. The organizations engaged in the development of this CRP are embracing the research for development paradigm now evolving within the CGIAR, as will those that will be involved in the future.

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 key dryland cereal production systems under increasing stress. Poverty, food insecurity and environmental degradation in the drylands are clearly exacerbating the situation.

VISION OF SUCCESS

The overall vision of success for DRYLAND CEREALS is three-fold: 1) significant and sustainable production increases, quality improvement and greater availability of these cereals for 15 million smallholder farmers in Asia and Africa; 2) measurably better livelihoods for these same households through improved productivity, more resilient and productive dryland crop/livestock systems, and better access to markets; and 3) notably enhanced nutritional value of these cereals. We will achieve our vision by implementing new forms of collaboration and partnership involving: the two CGIAR Centers that focus significant resources on these cereals (ICRISAT and ICARDA); major developed country partners (INTSORMIL in the USA and CIRAD andIRD in France); the Indian Council for Agricultural Research, which invests heavily in the four dryland cereals under this CRP; research partners that are part of the Generation Challenge Program projects on dryland cereals and integrated plant breeding; national agricultural research and extension systems in Africa and Asia; advanced research institutes in the public and private sector; and a wide range of development-oriented organizations working in targeted dryland areas.

For the first time, these partners will be working together to better coordinate their respective dryland cereals research-for-development (R4D) programs, and capitalize on opportunities for using common research and testing facilities, sharing results and knowledge, and providing a unified face to smallholder farmers regarding options for improving cereal production. We believe that encouraging such collaboration – and realizing the potential synergies and efficiencies collaborative efforts can entail – is the fundamental reason behind the CGIAR reform process and, especially, the development of CGIAR Research Programs.

Through its partnerships and farmer participation, DRYLAND CEREALS will add to the stability and productivity of its focus crops; improve human and animal health through enhanced nutritional content; and increase opportunities for smallholder farmers, especially women, to participate in markets for economic growth. These objectives address the CGIAR System Level Outcomes of Reduced Rural Poverty
(through greater market opportunities for dryland cereals), Improved Food Security (via more stable and higher production), Improved Nutrition and Health (by improving nutritional quality), and Sustainably Managed Natural Resources (through the better water- and nutrient-use efficiencies of dryland cereals). The value added from DRYLAND CEREALS that will accrue to smallholder farmers in targeted areas is expected to reach nearly US$ 2 billion by 2020.

Specifically, DRYLAND CEREALS will measurably increase the stability of production, productivity (yield per unit area), and production (total availability) of four major cereals – barley, finger millet, pearl millet and sorghum – grown in dry environments. These crops are important sources of calories and nutrition for more than one billion people living in Sub-Saharan Africa, Central and West Asia, the Middle East, and South Asia. During the next 6 years, DRYLAND CEREALS will generate at least 150 new varieties that have the traits preferred by farmers and consumers in target countries, varieties that will ensure production gains of at least 1%/year. The formal and informal seed sectors (public and private) will be mobilized to produce and disseminate quality seed of improved varieties to at least 15 million smallholders with particular attention paid to those 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, and hundreds of thousands of farmers and their families will be exposed to various aspects of dryland cereals production and marketing. Research capacity will be strengthened with the training of 60 PhD and MSc students.

DRYLAND CEREALS will plan for and implement a gender-focused approach to research for development in the drylands, with particular emphasis given to food processing and value-adding business opportunities for women.

Of the total resources requested for DRYLAND CEREALS, at least 23% will flow to the operating budgets of partners. We will link with – and leverage resources, information and technologies from – 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 value alliance”); 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 and the considerable strengths of a wide range of partners to focus attention on opportunities that exist in the drylands to improve the livelihoods of smallholder farmers and their families through food sufficiency, improved economic growth, and enhanced household nutrition.

**ADDRESSING CGIAR SYSTEM-LEVEL OUTCOMES**

DRYLAND CEREALS will contribute to all four of the CGIAR System Level Outcomes (SLOs) – reduced rural poverty, improved food security, improved nutrition and health, and sustainably managed natural resources – in the following ways.

**Reducing rural poverty (System Level Outcome 1)**

Over the past two decades, dryland cereals production and productivity have been rising steadily, and have increased more than the area sown to these crops in tropical and subtropical regions. This upward trend (0.5-1%/year) is encouraging, but not sufficient to even keep up with population growth, let alone to create marketable surpluses for generating additional income for smallholders. Experiments with dryland cereals on research stations, as well on farms, have clearly demonstrated that yields in many dry production ecologies could be two to four times higher with 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. Yet there is growing evidence that buyers interested in buying larger quantities of dryland cereal products face problems of availability.
The International Sorghum, Millet and Other Grains Collaborative Research Support Program

INTSORMIL will be a critical partner in DRYLAND CEREALS R4D efforts. 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. Its linkages with organizations in LAC will facilitate spillovers to dryland farmers in that region of R4D outputs and products, as well as the flow of relevant information and germplasm from the region into DRYLAND CEREALS.

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, foxtail and teff). 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.

Objectives

♦ 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.

Home processing of coarse dryland cereals to produce traditional foods is both difficult and time consuming, especially in urban settings. There is need for processed or value-added dryland cereal products that are easy and fast to prepare and have good shelf life. 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 developing options for increasing 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 mostly on-farm and by the very poorest people. Trapped in subsistence farming, the poorest 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. Thus, the poor will automatically capture the benefits generated by improving the production of these crops in the places where they live. DRYLAND CEREALS will work with farmers to identify their specific needs for improving varieties with the necessary benefits, identify new genes/traits through gene discovery, produce better stress tolerant germplasm with higher and more stable yields, exploit crop physiology to understand the basis for stress tolerance, develop and apply improved methodologies and tools for genetic improvement, establish effective seed and input systems that target smallholder farmers, and strengthen the capacity of partners and farmers.

DRYLAND CEREALS will develop new varieties that can better cope with abiotic stresses (by exploiting common root physiology), such as drought, high temperatures, poor soil fertility and high salinity, and that have better resistance to insect pests and diseases, while maintaining preferred grain and stalk quality and processing characteristics 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 risks for resource-poor producers. Low-cost agricultural packages will be developed to optimize yield of the new varieties and to enhance the dissemination of the technologies to these farmers. Even the poorest will benefit from such cultivars, as seed will be made regularly available to them through better formal and informal seed systems. Farmer-owned seed businesses or other emerging local seed enterprises in areas where the formal seed system is not well developed will fill the current seed-marketing gap. Concerted R4D is required to ensure that development actors, private sector entities, and national policy makers are aware of and can capitalize on the new opportunities and developments that new varieties can trigger.

Improving nutrition and health (System Level Outcome 3)
Malnutrition is a challenging and complex issue that requires close cooperation between various actors in the agricultural, nutritional, and health arenas (World Bank, 2006). In this context, DRYLAND CEREALS will contribute through its R4D to enhancing the nutritional value of dryland cereals. We will focus our efforts on producing five major nutrition-related outputs that will: 1) supplement our knowledge on dietary patterns, malnutrition, processing, and food safety, as well as reveal constraints, opportunities, drivers, and entry points for enhanced dryland cereal varieties; 2) develop cereal germplasm with better nutritional value (micronutrients, anti-nutritional factors), processing and storage characteristics; 3) develop tools and crop management practices to enhance nutritional value, food safety and post-harvest processing; 4) strengthen capacity, knowledge-sharing and awareness of stakeholders to better develop, promote, and disseminate nutritionally enhanced dryland cereals; and 5) produce evidence-based policy and regulatory advice that fosters the production and consumption of safe and nutritious dryland cereals.

The work that is proposed here builds on existing research efforts and partnerships through HarvestPlus, an important component of CRP 4, but also explores areas of research that will require new partners and collaborations (for example, biofortification of barley, finger millet and sorghum, enhanced processing, and longer shelf life). We anticipate achieving significant synergies by connecting this work with the integrated agriculture, nutrition, and health platform envisioned in CRP 4.
Sustainably managed natural resources (System Level Outcome 4)
While DRYLAND CEREALS will primarily target the System Level Outcomes on reducing rural poverty, increasing food security and improving nutrition and health, because these cereals are among the most efficient at using natural resources, our objective to improve abiotic stress tolerance will help ensure that further environmental degradation of the drylands is minimized. In addition, by improving the productivity and profitability of dryland cereals, farmers will be less likely to switch to other cereals, such as maize or rice, that are less efficient in the use of natural resources. Further reduction of environmental degradation can be achieved through the proposed research in optimizing dryland cereal/legume cropping systems, whereby dryland cereal production can be increased without significant requirements for additional nitrogen inputs.

DRYLAND CEREALS STRATEGIC OBJECTIVES
As outlined in the CGIAR Strategy and Results Framework, CRPs under Thematic Area 3 (Food Security) build on the CGIAR’s core competencies in improving the productivity and production of key commodities. DRYLAND CEREALS is therefore focused primarily on the core competencies of crop improvement, cropping systems and post-harvest technologies with significant efforts in production systems and price, trade and policy areas (Figure 1). Beyond the traditional core competencies, DRYLAND CEREALS also brings expertise and focus to new areas identified in the SRF such as climate change adaptation/mitigation and nutrition and health.

To properly focus our R4D agenda, we have structured DRYLAND CEREALS in terms of three key Strategic Objectives:

**SO 1: Increasing and sustaining the production of dryland cereals by smallholder farmers in Africa and Asia to achieve food sufficiency**

**SO 2: Contributing to economic growth by improving the profitability of dryland cereals production and increasing marketing options**

**SO 3: Optimizing nutritional value of dryland cereals for better health**

Each of these Strategic Objectives has been designed from a value-chain and system perspective to address one or more of the CGIAR System-Level Outcomes, as well as relevant key challenges and opportunities. Within each Strategic Objective, specific outputs have been defined (see Activities and Outputs) that are required along the impact pathway. These outputs then lead to outcomes at the immediate client level, and then to outcomes at the beneficiary (smallholder farmers) level (see Impact Pathway). Based on the relative importance of the dryland

![Figure 1. Core competencies of DRYLAND CEREALS](image_url)
cereals, as well as the number of smallholder farmers and poor, DRYLAND CEREALS will focus its efforts in four important regions of Africa and Asia (Table 1). As the CRP will produce essentially International Public Goods, spillovers to other regions will occur – especially in Latin America, given the partnership with INTSORMIL and other relevant actors.

Table 1. Regional focus of DRYLAND CEREALS

<table>
<thead>
<tr>
<th></th>
<th>WCA</th>
<th>ESA</th>
<th>CWANA</th>
<th>South Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dryland Cereals</strong></td>
<td><strong>Pearl millet, sorghum</strong></td>
<td>Barley, finger millet, pearl millet, sorghum</td>
<td>Barley</td>
<td>Barley, finger millet, pearl millet, sorghum</td>
</tr>
<tr>
<td><strong>Number of poor (&lt;US$ 1 per day)</strong></td>
<td>121 million</td>
<td>85 million</td>
<td>8 million</td>
<td>443 million</td>
</tr>
<tr>
<td><strong>Number of stunted children</strong></td>
<td>13 million</td>
<td>11 million</td>
<td>3 million</td>
<td>62 million</td>
</tr>
</tbody>
</table>

While all three Strategic Objectives are important in each region, emphasis will be given within each region given the existing challenges and opportunities (Table 2).

Table 2. Indicative priorities among strategic objectives

<table>
<thead>
<tr>
<th>Strategic Objective</th>
<th>WCA</th>
<th>ESA</th>
<th>CWANA</th>
<th>South Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO 1</td>
<td>***</td>
<td>**</td>
<td>**</td>
<td>**</td>
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<tr>
<td>SO 2</td>
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<tr>
<td>SO 3</td>
<td>***</td>
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<td>***</td>
</tr>
</tbody>
</table>

In WCA, greater attention will be given to improving the more sustainable production of dryland cereals (especially sorghum and pearl millet) under the extremely harsh conditions experienced by farmers in the region. In contrast, emphasis in South Asia will be on improving the profitability of dryland cereals as these crops shift in their use towards feed and fodder, and farmers are looking more towards market opportunities. WANA and ESA are more in transition with a range of farmers and opportunities, thus requiring a more balanced emphasis. Nutrition will be emphasized more equally across all regions given its critical importance in health. Each Strategic Objective is briefly described below, and in more detail in the Activities and Outputs section.

**Strategic Objective 1: Increasing and sustaining the production of dryland cereals by smallholder farmers in Africa and Asia to achieve food sufficiency**

DRYLAND CEREALS will focus much of its attention on helping smallholder farmers in the drylands of Africa and Asia to obtain higher and more sustainable production of dryland cereals, and in so doing meeting their food sufficiency needs with these crops. This will be achieved through seven major outputs: 1) better data on the major constraints and interventions required to the increased production of dryland cereals; 2) effective tools and methods to enhance the efficiency of dryland cereal improvement; 3) improved varieties with built-in abiotic and biotic stress tolerance; 4) dryland cereal hybrids for higher yields; 5) appropriate crop management options to sustain
production; 6) effective seed and other required input systems; and 7) increased knowledge and capacity of partners and farmers. The proposed research will build on existing activities, partnerships, and farmer participation, and will also explore new lines of research requiring new partners and collaborations.

**Strategic Objective 2: Contributing to economic growth by improving the profitability of dryland cereals production and increasing marketing options**

DRYLAND CEREALS will also focus on achieving significant and sustainable increases in the profitability and incomes of smallholder dryland cereal farmers, most of whom have mixed crop/livestock-farming operations. We envision greater market demand for dryland cereal grains and their “leavings” (stover, stalks and straw). Farmers will be better able to respond to increased demand by using the improved varieties and production technologies produced through Strategic Objectives 1 and 3. Strategic Objective 2 will lead to five key outputs: 1) knowledge and data on dryland cereal value chains related to feed and fodder for livestock, industrial uses, surplus marketing and food processing; 2) improved dryland cereals with characteristics that support the livestock revolution in marginal environments; 3) efficient dryland cereal production technologies to ensure that smallholder farmers can successfully engage with large-scale, industrial processors for a range of alternative end uses; 4) improved and innovative post-harvest and food processing technologies for promoting the dryland cereals among the traditional users, urban population and food processing industry; and 5) improved dryland cereal technologies for surplus production and models for strengthening market linkages.

**Strategic Objective 3: Optimizing nutritional value of dryland cereals for better health**

DRYLAND CEREALS will help reduce malnutrition of those living in the drylands, especially among women and children, through greater access to and use of nutritionally enhanced dryland cereals. This will be achieved by integrating nutritionally enhanced varieties combined with technologies (crop management and post-harvest) that increase the nutritional value of dryland cereals in the delivery systems developed in Strategic Objectives 1 and 2. Strengthening capacity, knowledge sharing, and raising the awareness of stakeholders will be used to mainstream the health value of dryland cereals. Strategic Objective 3 will produce five key outputs: 1) knowledge on dietary patterns, malnutrition, processing, and food safety, as well as constraints, opportunities, drivers, and entry points; 2) dryland cereal germplasm with better nutritional value, processing and storage characteristics; 3) diversified and improved strategies, tools and crop management practices to enhance nutritional value, food safety and post-harvest processing; 4) strengthened capacity, knowledge, and awareness of stakeholders to better develop, promote, and disseminate nutritionally enhanced dryland cereals with better processing and storage characteristics; and 5) evidence-based policy and regulatory advice that fosters the production and consumption of safe and nutritious crops by smallholder farmers.

Each of these objectives has as its foundation a number of major R4D projects that are currently funded and underway in various regions by the partners in the CRP (see Appendix XX for a list of the major projects being incorporated into DRYLAND CEREALS). Presently, however, there is insufficient interaction among these major projects to fully capitalize on potential research and development synergies. A primary function of each strategic objective, therefore, is to facilitate and draw on interactions among the partners involved in current projects, to identify gaps in current research and development efforts, and to propose ways to fill them to the benefit of smallholder farmers in dryland areas.


**THE VITAL IMPORTANCE OF THE DRYLANDS**

The CRP 1.1 on “Integrated agricultural production systems for the poor and vulnerable in dry areas” outlines well the importance and geographic distribution of the dry areas of the world. Over 40% of the global terrestrial area and nearly 50% of the developing world’s land area consists of drylands. These are the least-developed areas in the world as indicated by the Human Development Index (UNDP 2008) and as reflected by World Bank data on the geography of poverty. More than a billion poor people living in these areas depend on agriculture (including raising livestock) to survive.

Dryland areas are not uniform and should be thought of in terms of a moisture continuum. Mixed crop/livestock farming is common across much of this continuum. The very dry end of the continuum (i.e., under 150 mm annual rainfall) accounts for most of the drylands, and is generally used as rangeland. Towards the wet edge (350-400 mm annual rainfall in non-tropical drylands, 600-800 mm in tropical drylands) is where most of the people live, and dryland cereal crops predominate. Urban centers there serve as trade hubs for the fattening and marketing of livestock to the outside world. Thus, the interplay between crops and livestock is a central theme in dryland agriculture, and a major influence on the livelihood strategies of the poor, as well as on agro-ecosystem functioning.

In West and Central Africa (WCA) and East and Southern Africa (ESA), the drylands are among the poorest and most food-insecure areas on earth. Indicators of human deprivation and suffering in these areas include high childhood mortality rate, malnutrition, impeded brain and physical development in children, and others. Half or more of the people living in dryland zones earn US$ 1.25/day or less, and are considered to be living in “absolute poverty”. Africa’s children and the future of the continent are imperiled unless cereal production accelerates strongly (Rosegrant et al., 2001). Using data from the World Bank (2009), Walker (2010) determined that 12 out of 19 of the deepest “poverty trap” areas in sub-Saharan Africa were in the drylands (pockets where 60-90% of the population earn less than US$ 1.25/day).

South Asia also contains deep pockets of poverty. Although the absolute poverty rate in Asia’s drylands is less than in Sub-Saharan Africa (45% vs. 59%), twice as many absolute poor dryland inhabitants live in Asia than in Africa (443 vs. 205 million). Furthermore, dryland Asia outpaces Africa on the disturbing statistic of childhood malnutrition; 57% of children living in dryland areas in Asia are malnourished, while 43% of the children living in Africa’s dryland areas suffer from malnutrition.

Most of the inhabitants of these areas struggle to wrest a meager living from agriculture using subsistence cultivation methods. Tragically, they are missing out on large potential productivity gains that are biologically possible given the soils, crops and climates of these areas, as proven by decades of research across a wide range of dryland locations. Yields could potentially be doubled or even tripled from their current low levels of about 0.5 to 1 metric ton of grain per hectare, particularly through strong positive yield synergies between improved crop varieties, fertilizer and other management techniques (Srinivasarao et al. 2007; Tabo et al. 2007; Twomlow 2008). On a percentage basis, these potential gains are as large as those achieved in the famous Green Revolution for rice and wheat. Capturing even a modest portion of them would generate major impacts in reducing food insecurity and increasing incomes in these impoverished areas.

Given the stresses and variability of the rainfed drylands, however, a strategy that is more flexible and targeted than that employed during the Asian Green Revolution is needed – one that readily adapts to local environmental variability and risks. Integrated approaches are needed that create synergies between natural resource management and crop breeding (Twomlow et al. 2008). DRYLAND CEREALS will follow that path, working with many partners (including other CRPs) to develop and deliver adapted
and more nutritious crops, cropping system improvements to maximize productivity, and value-adding innovations that fit local conditions.

**IMPORTANT CEREAL CROPS IN THE DRYLANDS**

Barley, finger millet, pearl millet and sorghum are the major cereals produced by smallholder farmers living in dryland areas (see Appendix 1 for brief descriptions about these important crops). Figure 2 illustrates the strong overlap between the dry areas of Africa and Asia (the key target areas of the CGIAR Strategy and Results Framework and DRYLAND CEREALS) and where these cereals are grown. Sorghum and pearl millet are in high demand throughout the drylands of West, Central, East and southern Africa, as well as India. Finger millet is a major commodity being cultivated in East and southern Africa and southern India. Barley, especially for use as food and feed, is grown mostly in North and East Africa, West Asia and northern India.

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) 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, ethanol and dairy), which is providing increasing amounts of cash income to smallholder farmers.
**Figure 2.** The maps above show the drylands (top), and where dryland cereals are produced (bottom) in Africa and Asia. Delineation of the dryland areas is based on an aridity index that is the ratio of rainfall to evapotranspiration, where semi-arid areas are classified with an aridity index of 0.20-0.50 and the dry sub-humid tropics with an index of 0.50-0.65. Distribution of dryland cereals is based on spatially disaggregated area and production data for barley, millets and sorghum from IFPRI.

**WHY WORK ON THESE CROPS UNDER A SINGLE CRP?**

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

Taken together, the farm gate value of barley, finger millet, pearl millet and sorghum produced in Low Income Food Deficit Countries (LIFDCs) is at least equivalent to that of maize, and almost that of wheat (Table 3).

Given their substantial economic value and their importance as a mainstay for the hundreds of millions living in our target areas, relatively limited resources have been and continue to be allocated to dryland cereals. Working on them together enables us to create a much-needed critical mass in research aimed at achieving development impacts. Moreover, there are a number of common researchable issues associated with these crops, including but far from limited to:

- Determining the potential for increasing total biomass production and quality;
- 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 processing for better shelf life and nutritional value.
Table 3. Production (in millions of tons) and value of production (VOP in US$ billions) for dryland cereals (barley, millets, sorghum) worldwide and in low-income food deficit countries (LIFDC)\(^1\)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Production (MT)</th>
<th>VOP (US$ billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LIFDC</td>
<td>World</td>
</tr>
<tr>
<td>Barley</td>
<td>10.1</td>
<td>155.1</td>
</tr>
<tr>
<td></td>
<td>2.94</td>
<td>36.76</td>
</tr>
<tr>
<td>Millets (finger and pearl)</td>
<td>33.5</td>
<td>35.2</td>
</tr>
<tr>
<td></td>
<td>13.37</td>
<td>13.68</td>
</tr>
<tr>
<td>Sorghum</td>
<td>36.7</td>
<td>66.8</td>
</tr>
<tr>
<td></td>
<td>10.98</td>
<td>15.60</td>
</tr>
<tr>
<td>Total Dryland Cereals</td>
<td>80.3</td>
<td>257.1</td>
</tr>
<tr>
<td></td>
<td>27.29</td>
<td>66.04</td>
</tr>
<tr>
<td>Maize</td>
<td>99.4</td>
<td>826.2</td>
</tr>
<tr>
<td></td>
<td>26.80</td>
<td>222.68</td>
</tr>
<tr>
<td>Wheat</td>
<td>131.9</td>
<td>683.4</td>
</tr>
<tr>
<td></td>
<td>33.10</td>
<td>171.44</td>
</tr>
<tr>
<td>Rice</td>
<td>328.9</td>
<td>685.9</td>
</tr>
<tr>
<td></td>
<td>103.20</td>
<td>215.22</td>
</tr>
</tbody>
</table>

\(^1\) 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 wellbeing.

Barley, finger millet, pearl millet and sorghum all possess greater genetic yield stability and high levels of water and nutrient use efficiency than maize, rice and wheat, which 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 strong tolerance for or 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.

These crops have higher nutritional value in terms of important micronutrients (zinc, iron, calcium), and all are consumed primarily where they are produced, indicating high potential for direct impacts on livelihoods. In addition, there are very few alternative food production options for the large number of people living in dryland areas.

There is significant potential for capacity building that is relevant to all four crops, and there is a large number of largely disconnected 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.

Finally, the research for development efforts and outputs produced by DRYLAND CEREALS will be demand driven, synergistic, and will feature two-way linkages to the work being done in other key 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).
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.

Sustainable increases in productivity
Dryland cereals are among the hardiest crops grown today, 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. Table 4 (next page) provides an indication of the general priorities or emphasis DRYLAND CEREALS will give to various productivity constraints (and related traits) across all four crops.

Further improvement in the genetic potential of barley, millets and sorghum is essential for increasing grain yield and quality, as well as for improving the quantity and quality of their stover and straw. 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 need, and the commonalities among the crops, offers excellent opportunities for working on them as a group – capitalizing on both the critical mass afforded by DRYLAND CEREALS, but also the latent efficiencies and effectiveness of envisioned partnerships.

Adapting to climate change
One of the principal wildcards facing global agriculture is the probable impact of global warming. Climate change will have far-reaching consequences for agriculture, especially in rainfed areas (see CRP 7 for an in-depth analysis). 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, including maize, rice, and wheat, are now grown. Research aimed at meeting the eventual needs of smallholders in these regions, and the utilization of dryland cereal products as cost-effective alternatives, should be accelerated through increased investments and wider, more diverse partnerships in order to facilitate the ability to adapt to changing agro-ecological conditions. A close partnership with CRP 7 on Climate Change will ensure that DRYLAND CEREALS effectively targets improved dryland cereals to the conditions of new dryland environments and provides scientific data to enhance climate change models for dryland crops.

Sources of genes for stress tolerance
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, waterlogging, 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 a greatly expanded group of partners to advance strategic research to better tap stress tolerance in these crops.
Table 4: Priorities across dryland cereals for improving yield levels and reducing production constraints. The ratings are no star = unimportant, 1 star (*) = low importance, (***) = medium importance, (***) = high importance.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Barley</th>
<th>Finger millet</th>
<th>Pearl millet</th>
<th>Sorghum</th>
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<tbody>
<tr>
<td>Yield potential and stability</td>
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<tr>
<td>Hybrid technology</td>
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<td>Soil borne</td>
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<tr>
<td>Insect Resistance</td>
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<tr>
<td>Stem borers</td>
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<td>Sap-sucking insects</td>
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<td>Storage pests</td>
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<td>Parasitic weeds</td>
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<td>Abiotic Stress Tolerance</td>
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<tr>
<td>Drought</td>
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<td>Cold/frost</td>
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<td>Soil acidity</td>
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<td>Aluminum toxicity</td>
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<td>Soil salinity</td>
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<tr>
<td>Low soil fertility</td>
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<tr>
<td>Phenology</td>
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One of the most impressive findings of genomics research over the past decade has been the remarkable collinearity of gene sequences among different grass species, including cultivated crops (Tang et al., 2008; Zahn et al., 2008). Such gene orthology strongly suggests that collinear genes in different crops are evolutionarily related, and therefore probably functionally related. This in turn strongly suggests that genetic learning from one crop will be able to be effectively applied to another, generating large spillover benefits from investment in such research, including possible interspecies gene transfers.
Since the CGIAR’s work spans both the highly stress-tolerant (barley, millets, sorghum) and the less stress-tolerant cereals (maize, rice, wheat), 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, 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.

**Sustaining livestock**

As noted earlier, mixed crop/livestock smallholder farming enterprises are commonly found in dryland zones, and the nutritious crop residues produced by dryland cereals 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 minimal interest.

**A New Multi-Purpose Sorghum Variety for West Africa**

The sorghum variety ‘Soumba’ is one of a suite of new, shorter, photoperiod sensitive varieties that combines good grain quality from the local Guinea-race sorghums with shorter height from introduced breeding materials. Whereas farmers’ local varieties grow tall and woody, bullocks can eat the stems of this shorter variety. While the residue of local varieties is left in the field, farmers harvest the entire residue of Soumba and store it for dry-season feeding. Smallholders are increasingly growing Soumba because it produces good grain for their own consumption, as well as stover that will help their bullocks make it through the tough dry-season when fodder scarcity causes their animals to lose an average of 300 grams of body weight per day. Women farmers like this variety both because of its good grain quality, which is appreciated in the market and is easy to sell and, because there is less bird damage and stem breakage due to the variety’s shorter stems, they can wait to harvest it until after they finish bringing in their peanut crops.

The joint CIRAD-ICRISAT Sorghum Improvement Program in Mali produced Soumba sorghum. Its promise as a new variety was identified through an on-farm participatory effort involving farmers and researchers in yield testing a larger number of varieties under farmer-managed conditions. The Malian Research Organization, Institut d’Economie Rural, and ICRISAT, together with farmer organizations, jointly conducted the ‘32 Variety Trial’ with some 50 farmers across a dozen villages.

When Soumba was first chosen out of this trial, farmers considered it to be a ‘Project Variety’. Now the local farmer organization (ULPC) is producing certified seed of Soumba, and the organization’s president calls it ‘Our Variety’. And the extent of and potential for adoption is indicated by the fact that, after just a few years since it became available, 50% of the families living in one of the test villages (Magnambougou) now grow Soumba as a principal variety.

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 critically important to realize that such residues require no specific allocation of water and land, because they result 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 the best news is that there seems to be 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.

**Growing need for more nutritious products**

Increasing affluence is contributing to a rising demand in urban markets for value-added products, especially those with more nutritive value. In Kenya, for example, the demand for finger millet (consumed as “Uji”, a type of porridge) far exceeds supply, such that processors are forced to search for the cereal in neighboring Tanzania and Uganda. 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.
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 food product development of barley and consumer interest in eating such products.

Effectiveness of barley beta-glucans in lowering blood cholesterol and its low glycaemic index in diets for Type II diabetics is widely accepted. Barley is a rich source of tocols, which are known to be capable of reducing serum LDL cholesterol through their antioxidant action. Food products made from hulless barley are considered whole-grain foods. 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 also have better protein composition than rice, wheat or maize, and have higher fat content – and thus fat-soluble vitamins. Pearl millet and sorghum are gluten-free, and have low glycaemic indices. Consumers are learning more about the advantages of consuming these traditional cereals (see Box), and food-processing research is required to help ensure that some of the preferred, traditional dishes can be made more readily available in urban markets.

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 much smaller scale than for crops like rice, wheat and maize. 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, becoming 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 on 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.

**Lack of investment in the past**

Even though the CGIAR is one of the few organizations conducting R4D on key dryland cereals, the System has long focused the bulk of its resources on rice, wheat and maize. This has been an understandable and very rational allocation given the circumstances surrounding the origins of the System, as well as the socio-economic and agro-ecological realities that have prevailed since the CG was formed in 1972. While barley and sorghum have attracted significant private sector investment (mainly to capitalize on commercial markets located primarily in developed countries), other dryland cereals have not.

In general, government policies and production incentives in developing countries have favored public sector investments in the major cereal grains, and have tended to overlook the growing importance of dryland cereals. The result has been a notable lack of progress towards increasing the production, area, and yield of these crops, as is apparent in Appendix 1.

**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 use them, and engagement with those who deliver impacts to our ultimate beneficiaries – the poor of the dry tropics.

The DRYLAND CEREALS impact pathway has at its center the millions of smallholder farmers whose lives and livelihoods we are working to improve. The pathway(s) depicted in Figures 3 and 4 are built around a highly simplified, generic value chain for dryland cereals that depicts the key participants involved in contributing to or absorbing the value added along the chain – from R4D partners (NARESs, ARIs, IARCs and private sector entities), to development and delivery partners (which includes a range of NGOs, CSOs and private sector organizations), to smallholder farmers, to small- to medium-sized agro-enterprises and larger-scale agro-industries, through to rural and urban consumers. While this value
chain 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. We have intentionally simplified the value chain so that we can more clearly show the interplay of outputs (Figure 3) and outcomes (Figure 4) along it.

DRYLAND CEREALS is all about helping smallholder farmers increase the production, productivity and profitability of more nutritious dryland cereals. In order to achieve this goal, we must consider how the program’s outputs can produce desirable outcomes (defined as changes in behavior) on the different players along the value chain – and design our R4D activities accordingly. Those activities produce a range of outputs of various kinds: useful new technologies, knowledge, and innovations. They are demand (client) driven, derived in participatory ways with smallholder farmers, development partners and others.

![Figure 3. DRYLAND CEREALS outputs play out all along the highly simplified value chain shown here](image)

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 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 toward 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, prices will rise and the demand for additional surplus production will continue to increase.

Figure 3 shows in general terms the outputs envisioned from R4D institutes (top left) and the kinds of knowledge and policy advice (bottom left) that will help produce an enabling environment – knowledge about demand, production constraints, value-adding options, nutritional quality, and advice regarding better (smallholder-friendly) policies. Many of these outputs feed back to the R4D institutes themselves, enhancing their research and enabling them to set more appropriate R4D priorities. They also feed back to almost all the other players along the value chain – to development partners (i.e., options available for delivery, or identification of desirable alternatives), directly to smallholder farmers (for example, through smallholder participatory varietal selection schemes or community based seed systems), to SMEs and agro-industries (for example, new processing technologies or varieties with more desirable quality traits for malting and other industrial uses), and even directly to consumers (especially regarding knowledge about nutritional value and value-adding processing options).

Not surprisingly, gender considerations play 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 4, also a highly simplified schematic, is about the outcomes we are trying to achieve as we move along the dryland cereals value chain in both directions. Starting with smallholder farmers, as they gain exposure and experience with improved dryland cereals and begin to see the benefits of new, more productive and profitable technologies and agronomic practices, their demand for more affordable seed, fertilizer and information will increase. This in turn contributes to increased demand on the part of development partners for appropriate products from R4D partners, products they need to meet farmers’ needs. As R4D partners meet these demands, they work back along the value chain – enabling greater production of marketable surpluses, increasing marketing opportunities, lifting incomes, and improving food security and nutrition – eventually leading to higher-level outcomes.

DRYLAND CEREALS partners must take a holistic approach that considers 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.
RESEARCH FOR DEVELOPMENT ACTIVITIES

DRYLAND CEREALS is focused primarily on the core competencies of crop improvement, cropping systems and post-harvest technologies, with significant efforts in production systems and price, trade and policy areas (Figure 1). Beyond these traditional core competencies, DRYLAND CEREALS also brings expertise and focus to new areas identified in the Strategic Results Framework (SRF) such as climate change adaptation/mitigation and nutrition and health.

DRYLAND CEREALS is structured around three key Strategic Objectives:

SO 1: Increasing and sustaining the production of dryland cereals by smallholder farmers in Africa and Asia to achieve food sufficiency

SO 2: Contributing to economic growth by improving the profitability of dryland cereals production and increasing marketing options

SO 3: Optimizing nutritional value of dryland cereals for better health

Each of these Strategic Objectives is designed from a value-chain and system perspective to address one or more of the CGIAR System Level Outcomes, as well as relevant key challenges and opportunities. Within each Strategic Objective, specific activities and outputs have been defined. These will lead to outcomes at the immediate client level, and then to outcomes at the beneficiary level, i.e., smallholder farmers.
STRATEGIC OBJECTIVE 1 – INCREASING AND SUSTAINING THE PRODUCTION OF DRYLAND CEREALS BY SMALLHOLDER FARMERS IN AFRICA AND ASIA TO ACHIEVE FOOD SUFFICIENCY

Vision of Success
Our vision of success for DRYLAND CEREALS Strategic Objective 1 is smallholder farmers in the drylands of Africa and Asia obtaining higher and more sustainable production of dryland cereals through the adoption of new varieties and low-cost agricultural packages, thus meeting their food sufficiency as provided for by these crops. Small and medium-sized seed producers, including farmer and community-based seed organizations, will seize opportunities created by an increasing demand for new varieties and provide affordable seed to farmers. The best and low-cost agronomic practices for optimizing yields in farmers’ fields will be well documented, appropriately communicated, and increasingly adopted by smallholder producers.

To achieve these successes at the farm level, variety development activities will be driven by clients’ needs and preferences, elaborated in a collaborative manner with farmers and their professional associations for specific groups of target production ecologies. Beyond success at the farm level, and to achieve a quantum jump in productivity without increasing risk, the association of phenotypic with genotypic information for the dryland cereals will unravel the genetic basis underlying enhanced tolerance to drought, heat, salinity and resilience to other stresses, resistance to diseases and pests, enhanced nutrition and market value, and improved feed/forage traits. Such a vision is rooted in the completion of the whole genome sequences for the major dryland cereals, and integration of this information with that from other important crops for which sequences are available. Whole genome sequencing will also provide for more complete analysis of the gene/trait diversity available in the dryland cereal genebanks, opening these to more effective use in research and breeding. Ultimately, such information and analysis tools provided in globally accessible and geospatially referenced data systems will offer the elements needed to implement molecular breeding approaches resulting in increased breeding efficiencies and the ability to combine multiple complex traits into farmer-preferred varieties.

Challenges and Opportunities
Strategic Objective 1 provides a number of opportunities through the unique partnership between advanced institutions, leading national programs and CGIAR Centers. These include:

- Better coordinated efforts to identify, characterize and harness critical genes/traits within and across dryland cereals (e.g., root physiology) by learning from genomics, and comparative genotypic and phenotypic analyses;
- Increased likelihood of developing and disseminating improved germplasm that can help mitigate the effects of climate change;
- Improved efficiencies of national and international breeding programs through the adoption of more integrated, client-oriented and information-based breeding platforms;
- Multi-site evaluation of all dryland cereals to better identify well-defined adaptation domains for specific varieties that perform well across a range of environmental conditions;
- Coordinated approaches to study specific production systems of smallholder farmers, including women, and key environmental effects on plant development to better understand the basis of specific adaptation;
- Tapping of heterosis in dryland cereals for increased yields and enhanced resistances/tolerances to diseases, pests and abiotic stresses;
- More effective seed systems (formal and informal) that provide smallholder farmers better access to and availability of high-quality seed of dryland cereals; and
• Linkages with the USA, Australian and Indian national program projects to enhance the improvement and dissemination of dryland cereals.

Of course, a number of challenges remain and will be addressed through the opportunities outlined above. Such challenges include:

• Increasing the production of dryland cereals under extremely harsh conditions that face smallholder farmers;
• Lack of effective linkage of research to dryland farmers’ seed systems;
• Lack of agricultural support services, like extension services or production credit facilities in dryland areas and other input supply systems that smallholder farmers have ready access to; and
• Rapid transformations in land access rights in some areas and conflicts around land use rights in many dryland areas in Sub-Saharan Africa;
• Aging NARES research teams working on dryland cereals in Sub-Saharan Africa;
• Poor coordination between emergency food and seed supply and agricultural development activities in areas with high risk of crop failure.

Outputs, Activities and Key Milestones

Achieving our vision of success for Strategic Output 1 will hinge on a number of partnerships with NARESs, ARIs, various private sector organizations and development partners (as described in the Partnership Section), and with CRPs 1.1, 2, 3.1, 3.2, 3.3, 3.5, 3.7 and 7 (as described in the Interactions with other CRPs Section). We will focus our collaborative research efforts on producing seven major outputs: 1) understanding the major constraints to the increased production of dryland cereals in specific production systems; 2) developing the tools and methods to enhance the efficiency of dryland cereal improvement; 3) increasing abiotic and biotic stress tolerances; 4) exploring heterosis for higher yields; 5) improving crop management options; 6) establishing effective seed and other required input systems; and 7) strengthening the knowledge and capacity of partners and farmers. Work on each of these will build on existing research activities and partnerships, but will also explore new lines of research requiring new partners and collaborations.

**Output 1.1 Priority target interventions for dryland cereals based on farmer and consumer demands, past experiences of varietal development and dissemination, identified production system specifics and biophysical and socio-economic dynamics of the production systems**

This output will enhance the existing dryland cereal data resources by building a dynamic data repository and analysis system that can be used by all researchers to set priorities for dryland cereal research. Insights gained from participatory production system diagnostics with farmers and other stakeholders, local seed system analyses and data collected during collaborative farm-based research will be the basis for this repository. A significant percentage of varieties and associated technologies of dryland cereals are never widely adopted by smallholder farmers. The variety development process – from identifying desirable traits to the widespread adoption of improved varieties – is long, it is critical to establish priorities based on farmer preferences and the latest information available. We will partner with farmer organizations as well as leading institutions in geospatial tools and satellite imagery technology to develop the necessary geo-referenced databases and analysis systems for dryland cereals. These will incorporate more dynamic and global datasets and provide global public access to the analysis tools. We will pay particular attention to gender, incorporating gender-disaggregated data and analysis at all stages. Finally, we will use the established information tools to design appropriate gender-sensitive methodologies to better involve smallholder dryland cereal farmers in the initial development of production packages, and in the actual production and marketing of dryland cereals.
Activities

- Characterization of the production systems to establish the recommendation domains (using, for example, farmer participatory and geospatial tools with satellite imagery technologies);
- Analysis of the past experiences with variety release and adoption to establish challenges and opportunities that must be addressed;
- Identification and prioritization of the dryland cereal traits and trait combinations that address the identified biophysical, socio-economic and market challenges and opportunities, mapping them to specific domains;
- Gender disaggregated analysis of the roles, needs and comparative advantages of women and men along the dryland cereal food value-chain from production to consumption;
- Development of methodologies to effectively involve the most marginal dryland cereal farmers, especially women, in crop development programs as partners or clients; and
- Development of methodologies and tools to effectively provide smallholder dryland cereal farmers, especially women, with better access to farming and marketing information.

Key Milestones (2012-2014)

2012

- Assemble database on relevant variables at disaggregated state/province/district level to delineate and characterize the target domains
- Geospatial analysis of different dryland cereals production systems in North and East Africa is completed
- Framework for documenting farmer participatory production systems diagnostics in a readily accessible format for a variety of users, with options for refining the content gradually
- Socioeconomic baseline survey and farmer participatory constraint analysis is completed and livelihoods of rural communities in at least 3 major production systems are fully characterized
- Monitoring system and tools identified for regular documentation of key changes in production systems and farmer livelihoods
- Comparative analysis of current technology delivery systems (extension, variety release, seed system, appropriate communication tools through participatory research) in identified major dryland cereals farming systems and policy environments completed
- Women’s roles and knowledge of agronomic management and post-harvest utilization of dryland cereal crops analyzed for major production systems in target regions

2013

- Geospatial analysis of different dryland cereals production systems in West, Central and South Asia completed
- The ex ante impacts of dryland cereals breeding on rural income and other welfare indicators evaluated for at least one major region
- Guidelines for women’s participation in on-farm trials developed
- Alternative more effective technology delivery systems compared to current delivery systems for major dryland cereals regions

2014

- The ex ante impacts of dryland cereals breeding on rural income and other welfare indicators evaluated for at least one additional major region
Output 1.2 Tools and methods to enhance the efficiency of global dryland cereal improvement

We will harness the power of client orientation, genomics, up-to-date information technology, and systems biology to enable quantum leaps in the efficiency of dryland cereal research and breeding efforts globally. This is both an ambitious but necessary undertaking if we are to meet the urgent need to improve stability and productivity by effectively mining genetic diversity from germplasm collections, broadening the genetic base of breeding germplasm using primary, secondary and tertiary gene pools, increasing abiotic tolerances and biotic stress resistances, and expanding research on and utilization of dryland cereal species.

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 on new opportunities through advanced science. DNA sequencing technologies, for example, have evolved to the point where “personalized” genomics is now possible. 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 new genome sequencing technologies and associated data analytical platforms drive down the costs of marker-data generation and management.

Coupled with this is the need to use information technology and bioinformatics to provide crop breeding programs a centralized and functional portal to access the 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 being developed by the Generation Challenge Program). Such integrated portals should also incorporate geospatial 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.

Activities

- Guidelines for more effective technology delivery system developed and communicated to policy makers

- Assembly of partial and whole genome sequences of the dryland cereals and locate highly conserved regions containing possible common roles across species;

- Development of multi-allelic populations, such as Multiparent Advanced Generation Inter-Crosses (MAGIC) and Nested Association Mapping (NAM);

- Developing, assembling and using TILLING and EcoTILLING populations and approaches to identify new alleles in germplasm collection for key traits

- Development of multi-allelic populations, such as Multiparent Advanced Generation Inter-Crosses (MAGIC) and Nested Association Mapping (NAM);

- Utilization of new information management systems for genotypic and phenotypic performance data, including from farmer evaluations of breeding materials and germplasm collections;

- Document experiences with recurrent selection, population improvement, dynamic geneepool management and farmer participation with appropriate datasets as a basis for evaluating new options for gains in efficiency;

- Establishment and utilization of an integrated phenotyping platform for adaptation to low soil-phosphorus availability, Aluminum toxicity, drought, heat and salinity tolerance;
- Development of doubled haploid breeding methods for the rapid development of homozygous material for mapping and breeding programs;
- Development and promotion of an Integrated Breeding Platform (IBP) for dryland cereals to enhance the development of better adapted varieties through genome and information-based breeding; and
- Training of scientists and students (MSc, PhD) in the use and integration of new technologies.

**Key Milestones (2012-2014)**

**2012**

- Key gaps of missing/novel diversity including in wild relatives identified
- Reference germplasm sets for dryland cereals available for distribution to partners
- Fingerprinting (genotyping) and phenotyping databases functional and accessible globally
- Information on existing TILLING populations collated, and candidate genes for Eco-TILLING identified
- Information on existing mapping populations assembled and made publicly available
- Resources and partners for genome sequencing of dryland cereals identified
- New marker-based breeding projects initiated with national breeding programs and links with integrated breeding platform facilities established
- Effective field phenotyping methods for adaptation to low-Phosphorus and to high Aluminum and salinity identified

**2013**

- Additional collecting missions to collect missing/novel diversity including in wild relatives conducted
- Phenotyping network established for dryland cereals across partners and dryland crops
- Reference sets of dryland cereals distributed to partners and characterized with shared phenotyping protocols and facilities
- Target Populations of Environments (TPE) for characterization of genetic resources and MET evaluation of breeding material established
- Proof-of concept for genotype-by-sequencing for cost-effective whole-genome marker data generation established with some dryland cereals
- Improved germplasm using novel molecular breeding approaches
- Structure of repository for documenting breeding methods for dryland cereals identified with a wide range of partners and potential users
- Screening techniques refined for identifying sources of resistance to abiotic (e.g., terminal drought, adaptation to low phosphorus availability, salinity, Aluminum toxicity) and biotic stresses (e.g., downy mildew, blast, storage pests, root diseases, stem borers, shoot fly, *Striga*) for at least 3 crop/constraint combinations
- Cereal breeders in at least 4 target countries use molecular tools for selection decisions

**2014**

- Draft genome sequences produced for additional dryland cereals
- Genotyping by sequencing for some dryland cereals operational and genomic selection initiated
- Value of controlled environment phenotyping for low-P tolerance and Aluminum toxicity and salinity tolerance for predicting on-farm responses assessed
Studies initiated to compare efficiency of specific breeding methods combining conventional, farmer participatory and genetic tools for specific situations for dryland cereal improvement.

**Output 1.3  Improved dryland cereal varieties with increased abiotic stress tolerance and biotic stress resistance for higher, more stable and sustainable yields**

Low available soil phosphorus (3-5 ppm) is common in West Africa and is a major limitation to productivity. However, barley, pearl millet and sorghum manage to produce grain under low-input conditions. Under these same conditions, maize fails without fertilization, even if there is sufficient water. However, reduced and delayed growth in poor soils lowers productivity and leaves crops more vulnerable to other stresses, such as drought. Thus, exploiting genetic adaptation to low-phosphorus conditions could contribute to both higher and more stable yields, as well as improve the economic returns to phosphorus fertilization.

Water stress, poor soil, heat waves and salinity are common characteristics of the areas where dryland cereals are grown. Often these stresses are concomitant and create havoc. For instance, low phosphorus levels in soil delays flowering, and this can have dramatic consequences for crops whose phenology is determined by the end of rains (due to photoperiod sensitivity). Unfortunately, there has so far been virtually no research on how to improve crops to withstand such combinations of stresses. In addition, the intensity of some of these stresses, such as heat and drought, varies across seasons. Therefore, crop resilience against these abiotic stresses is needed to ensure that farmers harvest at least some level of output every year.

Dryland cereals already have a certain degree of adaptation to these stresses. For example, pearl millet is among the crop species that require the least amount of water, while barley is among the top most salinity-tolerant crops. There is a wealth of variation for stress tolerance in dryland cereal germplasm and large scope for plant improvement. In addition, crops that are already endowed with adaptive traits opens the door to tapping these traits for use in other important but less stress-tolerant cereal crops. SO 1 also opens the possibility to tackle common constraints with a concerted approach across crops, focusing on what the partners of DRYLAND CEREALS do best. For example, using common protocols to assess the responses of different crop species to drought allows the comparison of adaptive
mechanisms across species, and subsequently for more systematic screening of critical traits across crops.

Pests and diseases of dryland cereals have very specific and evolving distribution patterns. To reduce risks of crop losses due to the outbreak of specific pests (e.g., pearl millet head miner and sorghum shoot fly, stem borers, midges, and head bugs), or due to the development of new virulent strains of diseases (e.g., downy mildew on pearl millet, anthracnose on sorghum, and blast on finger millet), breeders need to have effective tools at hand to identify new sources of resistance, and to monitor the evolution of specific pests and diseases. Moreover, seed treatments for controlling seedling diseases and some systemic infections can be very effective, and can contribute as much as 20% to yield gains. But seed treatment products often require specialized handling for safety, and thus are not often available to farmers who use their own seed.

**Activities**

- Identification of new traits, better understanding of physiological basis, and improvement of screening methodologies to better predict crop performance under stressed target environments;
- Assessment of trait values on yield using crop simulation modeling to define breeding targets;
- Mining of genetic diversity for important adaptation traits to identify source materials;
- Application of more effective phenotyping methods to identify germplasm with exceptional adaptation to low-phosphorus and high Aluminum and salinity conditions;
- Transfer of adaptive traits into improved germplasm (pre-breeding) to develop diverse and targeted breeding materials;
- Development of new and diverse varieties with adaptation and farmer-preferred traits from new sources of genetic diversity;
- Organization of yield stability and adaptation trials of developed material for major production systems using Multi-Environment Trials (MET) and gender responsive participatory approaches;
- Development of strategies to address the different needs of women and men in research and technology development;
- Monitoring evolution of new virulent strains of pathogens of dryland cereals; and
- Monitoring and evaluation of the new methodologies and strategies to improve their effectiveness over time.

**Key Milestones (2012-2014)**

**2012**

- Analysis and synthesis of multi-environment data sets
- MET sites for the 4 crops stratified based on available biological and climatic data to determine key benchmark sites or zones for future testing
- Random-mating sorghum population for P-efficiency completed
- Interspecific crosses in barley executed
- Stakeholders with breeding programs consulted to contribute materials with desired traits and adaptation information for regional testing
- Virulence change in the downy mildew pathogen monitored and resistance sources effective against new/changed virulence identified
2013

- Germplasm with superior adaptation to low-Phosphorus, high Aluminum, high salinity soils, reproductive heat tolerance and/or drought tolerance identified
- Linked with Output 1.1, establish and provide biophysical and socio economic characteristics of identified major production systems
- Regional variety and hybrid nurseries composed for evaluation in the target AEZ and production systems using benchmark sites
- Additional interspecific crosses and backcrosses in barley executed
- Participatory varietal selections conducted to determine varieties/hybrids to be promoted to the National Performance Trials and at least 40% of the participants in Participatory Varietal Selection are women
- Quality assessments conducted for all released and elite cultivars to identify lines with specific crop end use attributes
- Selection of promising lines within prominent landraces
- Variation in the blast pathogen of pearl millet and finger millet assessed and sources of resistance identified for utilization in breeding program

2014

- Regional and sub-regional databases for adaptation of varieties are established
- Evaluation of promising lines and multilines selected from landraces
- Progenies derived from populations tested for yield and yield stability
- Marker-assisted QTL transfer of complex resistance traits into farmer preferred varieties evaluated, also on-farm, for at least two different traits

Output 1.4  **Heterosis (hybrid vigor) for higher and more stable yields of dryland cereals**

Hybrids are crop cultivars that capitalize on the phenomenon of hybrid vigor. For farmers, these cultivars have more vigorous growth in the face of abiotic stresses such as drought, poor soil fertility and salinity, and thus higher yields of both grain and fodder. Dryland cereal hybrids can be developed that have better resistance to insect pests and diseases, while maintaining preferred grain quality and processing characteristics. Farmers, even the poorest, will benefit from such cultivars if seed is regularly available to them. They will also benefit from the ‘yield jump’ that is possible in hybrids versus incremental improvements in open pollinated varieties.

Smallholder dryland cereal farmers will be involved in shaping the trait combinations of their new hybrids. Special emphasis will be given to improved yield stability under the most difficult production conditions: high temperatures, low and erratic rainfall, low soil phosphorus, and *Striga* or downy mildew infestations. These ‘farmer-friendly hybrids’ will also have the traits farmers need for local adaptation and local uses. Pearl millet and sorghum hybrids represent the majority of rainy season dryland cereal production in India. New hybrids produced in W Africa using local and regional but genetically diverse germplasm are showing yield advantages of over 20% in on-farm conditions (see report on McKnight Foundation Germplasm Project, CCRP Website). These gains are large enough to justify the costs of hybrid seed multiplication and marketing. Smallholder farm families can produce seed, as the female seed parent will be stable in its male sterility, and will retain its high yield potential. The male parent will also be highly productive and will produce grain that meets local quality standards for food, so that even smallholders who are keen to market hybrid seed can do so, while maintaining quality food production in the same field. Farmer-owned seed businesses, or other emerging local seed companies in areas
where the formal seed system is not well developed, will fill the current seed-marketing gap but need technical assistance for initiating hybrid seed production.

Research will be done, not only to develop the new hybrids itself, but also to ensure that the benefits reach those who need it most – women farmers and those struggling to overcome recurring food-insecurity. This will require local partnerships focused on sustainable improvements in soil fertility, communications, social science and economics research, market access, and various food processing initiatives and technologies. Clearly, researchers operating alone cannot achieve the kind of changes envisioned here. Concerted R4D is required to ensure that development actors, private sector entities, and local policy makers are aware of and can capitalize on the new opportunities and developments that “smallholder farmer-friendly hybrids” can trigger.

Activities

- Establishment of heterotic groups to improve the efficiency of hybrid development, using molecular as well as quantitative genetic tools;
- Development of new reliable male-sterile female parents and fertility restoring male parents (lines and populations) for different target agro-ecological zones, while respecting the heterotic groups defined previously;
- Development of hybrids that respond to market demand, farmers’ needs and preferences (women and men), industry/market requirements for grain, stalk traits, and have a clear productivity advantage over existing varieties and hybrids;
- Design of hybrid breeding and evaluation protocols for effective and efficient multi-location evaluation in specified target;
- Design and testing of recurrent selection of male- and female-pools for enhancing source materials for hybrid parent development for maximizing heterotic, complimentary germplasm pools;
- Exploitation of the variation for out-crossing rates in the genus *Hordeum*, including the effect of floral behavior and its genetic control, using both morphological or biochemical markers;
- Development of populations with increased out-crossing rate using recurrent selection in *H. vulgare*; and
- Development of effective hybrid seed production methods and support partners in launching commercial production of dryland cereals.

Key Milestones (2012-2014)

2012

- Identification of superior parents for diversification and donor parents
- Analysis of genetic diversity patterns of prior studies and hypothesizing parental pools
- Diversification of hybrid parental lines for different regions
- Target zone and required traits for breeding populations and future hybrids identified

2013

- Sorghum hybrids for new zone (700-800mm) in West Africa developed
- Marker-assisted pyramiding of genes for resistance to biotic stresses and adaptation to abiotic factors achieved for two dryland cereals
- Marker-assisted backcrossing schemes developed for converting maintainer line into male-sterile lines for use as female parents for two dryland cereals
- New pearl millet and sorghum populations initiated for recurrent selection
- Recommended hybrid seed production designs for specific regions

**2014**

- Testcrosses for fertility reaction, identification of maintainer lines and restorers
- New diversified maintainer lines (sorghum and pearl millet) identified for Asia and Sub-Saharan Africa
- Markers identified for new sources of resistance or adaptation traits for at least 3 crop constraint combinations

**Output 1.5  Crop management options for effective and affordable Striga, soil fertility, intercropping and weed management**

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). However, crop and yield physiology of the dryland cereals, especially in some of the higher potential areas, is poorly understood. Farmers and breeders will benefit from more specific insights into the relationships between photoperiod sensitivity and rate of growth and development. While hybrids, along with increased market access, will provide farmers the incentive to invest in soil fertility improvements, research is required to identify suitable options for specific situations, work that will be done in close cooperation with CRP 1.1.

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. 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.

The parasitic weed *Striga* is of particular importance in poor soil conditions and its control requires integrated genetic and crop-management interventions. Transfer of resistance to farmer-preferred varieties using marker assisted backcrossing is ongoing as a proof of concept. A suite of crop management options have been identified that contribute to *Striga* control and local choice of specific components through farmer participatory processes is ongoing (see Box, next page).

**Activities**

- Determination of low-cost, low-external inputs sustainable management options;
- Development and validation of water-use efficient technologies targeting production domains;
- Validation of integrated technologies (crop cultivars and management options); and
- Identification of best-bet integrated technologies for scaling out.

**Key Milestones (2012-2014)**

**2012**

- On station testing of different rates of micro-doses of fertilizers are evaluated and optimum rates are established
around six specific objectives that address market chain and delivery constraints/opportunities, as well as the genetic and production systems specific to the three crops:

- Target opportunities for technology development and delivery to maximize adoption and impacts of innovations on livelihoods in WCA, ESA and SA;
- Improve sorghum cultivars and management options to increase productivity in WCA, ESA and SA;
- Improve pearl millet cultivars and management options to increase productivity in WCA and SA;
- Improve finger millet cultivars and management options to increase productivity and production in ESA;
- Discover and develop improved market strategies for sorghum, pearl millet and finger millet to stimulate adoption of improved technologies in WCA, ESA and SA; and
- Enable technology adoption of sorghum, pearl millet, and finger millet by improving access to inputs and markets differentiated according to both women and men’s needs in WCA, ESA, and SA.

**2013**

- Best integrated technologies are identified and promoted in the targeted areas and scaled out to other areas with similar production systems based on results from Output 1
- Options for soil-water managements and microdosing of fertilizers tested are demonstrate on-farm
- Participatory methods suitable for testing integrated technologies are identified and used
- 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
- IPM/IDM systems for management for at least three crop pest/disease combinations developed for specific production ecologies

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**Bringing HOPE to the Drylands of Sub-Saharan Africa and South Asia**

DRYLAND CEREALS will capitalize on and increasingly integrate R4D projects now underway in dryland areas across Asia and Africa. One such project – “Harnessing Opportunities for Productivity Enhancement of Sorghum and Millets in Sub-Saharan Africa and South Asia”, known simply as the “HOPE project” – is funded by the Bill and Melinda Gates Foundation and managed by ICRISAT. The project focuses on dryland areas in West/Central Africa, Eastern/Southern Africa and South Asia that provide major opportunities for alleviating food insecurity and poverty. It is a collaborative effort aimed at discovering, developing and delivering improved technologies for increasing the productivity of sorghum, pearl millet, and finger millet.

Organizations providing seed, fertilizer, credit, and know-how are working with producers, buyers, and marketers so that crop production is made possible by the availability of essential inputs, and is driven by market demand. Synergies between improved crop varieties and fertilizer, farmer participation, and gender equity receive particular emphasis.

The Hope project’s vision of success is to increase sorghum, pearl millet and finger millet yields for targeted and gender-differentiated farmers in Sub-Saharan Africa and South Asia by 35-40% in its first four years. This is being done through the development and delivery of improved cultivars and associated management practices. Technology adoption is motivated by the development of markets and value chains, from input supplies to output markets. Improved, stress-tolerant and nutrient-responsive sorghum and millet varieties will reach 110,000 households in Africa and 90,000 in South Asia during the project’s first four years. Within ten years, it will benefit about 1.1 million households in Sub-Saharan Africa and 1.0 million in South Asia.

The project’s overall goal is to increase the productivity of dryland sorghum, pearl millet and finger millet production systems in targeted areas, increasing household incomes and food security. To do this, HOPE project work is organized around six specific objectives that address market chain and delivery constraints/opportunities, as well as the genetic and production systems specific to the three crops:

- Target opportunities for technology development and delivery to maximize adoption and impacts of innovations on livelihoods in WCA, ESA and SA;
- Improve sorghum cultivars and management options to increase productivity in WCA, ESA and SA;
- Improve pearl millet cultivars and management options to increase productivity in WCA and SA;
- Improve finger millet cultivars and management options to increase productivity and production in ESA;
- Discover and develop improved market strategies for sorghum, pearl millet and finger millet to stimulate adoption of improved technologies in WCA, ESA and SA; and
- Enable technology adoption of sorghum, pearl millet, and finger millet by improving access to inputs and markets differentiated according to both women and men’s needs in WCA, ESA, and SA.
2014

- Water use efficient technologies are tested on-farm using participatory methods
- Location-specific improved production technologies are tested (crop cultivars and soil-water-fertility management) for productivity and weed management
- 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
- 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
- Weed management options compared in at least 2 production ecologies, considering women’s needs, including monitoring health and environmental effects of increasing herbicide use in dryland cereal cultivation
- Tools and local capacity developed and disseminated to monitor dryland cereal mycotoxin contamination in at least two production systems with increased risks (in close collaboration with the CRPs on Grain Legumes, Maize, and Nutrition and Health)

Output 1.6  
Effective seed systems for smallholder farmers

A “seed system” is a broader concept of technological, organizational, institutional, regulatory, and policy framework within the variety development-seed production-seed use continuum. Irrespective of the crop, its overall performance and efficiency can be measured by a combination of factors in the ‘seed chain’ from developing well adapted farmer preferred varieties to building an effective seed market to reach farmers. Weak seed delivery systems are often cited as a major constraint for adoption of dryland cereal varieties (Diakité et al., 2008; Aw-Hassan et al., 2008) for realizing the impacts of international and national research in farmers’ fields.

Given the complexity of environments and the diversity of crops, there is no one size fits all in developing one model seed delivery system for dry land cereals. Efforts will be made to improve the efficiency and the effectiveness of the national seed sector to create a diverse and competitive delivery system, including formal public and private seed sector and new innovative informal approaches involving farmer groups (associations, cooperatives), individual seed producers and NGOs operating in target countries.

Activities

- Synthesis of tested seed delivery models to draw lessons and experiences;
- Assessment of gender roles and issues within existing seed systems by characterizing the typology of farmers, identifying gaps and qualifying the mechanisms ensuring access;
- Designing, testing, promotion and assessment of the effectiveness of alternative seed delivery models in targeting different farmers that contribute to a more gender equitable access to seed;
- Strengthening the availability and access to early generation seeds (breeder and basic) of dryland cereals;
- Exploration and development of business models and institutions that can provide equitable access to credit to facilitate farmers’ enhanced use of inputs;
- Provision of technical and scientific support to rationalization and harmonization of seed regulations and policies;
Assessment of the differential impact of policies and seed governance systems on rural women and men;

Provision of policy recommendations to enhance gender-equal access to and control of seed for food sufficiency; and

Development of information networks to facilitate farmers’ and other stakeholders’ access to cultivar, management, and market information with a gender approach.

Key Milestones (2012-2014)

2012

- Review of alternative seed delivery models is conducted and results are available
- Study of gender issues in accessing seed systems is available
- Review of existing breeder and basic seed production is conducted and results are available
- Review of existing institutions and credits for agricultural inputs (seeds, fertilizers) is conducted and results are available
- The e-consultation to reach consensus among partners is initiated
- Impact of seed policies on women and men is assessed
- On-going rationalization and harmonization efforts in different sub-regions (e.g. COMESA, ECOWAS, SADC, ECO, etc.) receive technical support

2013

- Policy recommendations to enhance gender-equal access to seed are developed
- National studies on the technical efficiency of public and private sector dryland cereal seed production are completed in at least five countries
- Critical bottlenecks identified regarding technical efficiency of dryland cereals seed production and marketing in selected countries in Sub-Saharan Africa (e.g., barley, sorghum and millet in Ethiopia, Morocco, and West and Central Africa)
- Impact of seed policies on women and men farmers is assessed in at least 2 target production systems

Partnering with Farmers for Seed Delivery

Weak seed delivery systems, which limit the adoption and diffusion of new technologies, are often cited as a major constraint to realizing field-level impacts of investments in international and national research. This is a chronic problem for dryland cereals, particularly barley, which is grown in harsh dry, complex and risky environments primarily by smallholder subsistence farmers in remote and isolated regions. Poor infrastructure, limited access to government services, poor linkages to markets, and farmers’ being risk averse further exacerbate the problem. At present, neither public seed corporations nor private seed companies will provide much needed seed delivery services.

ICARDA is promoting a flexible alternative. Village-based seed enterprises (VBSEs) that are ‘owned’ and managed by farmers are both technically feasible and economically viable enterprises. These small-scale businesses focus on decentralized seed production and marketing, particularly to serve smallholder farmers in marginal, remote and isolated areas. These enterprises are participatory in that they mobilize and empower farmers in target environments. They are decentralized and multiply locally adapted and farmer-preferred varieties. They are business oriented, linking seed production to demand from local communities. They are cost effective, minimizing transaction costs and thus reducing seed prices. They focus on producing seed quality that is appropriate to farmer requirements. They use appropriate technology, such as low-cost mobile cleaners/treaters to improve seed quality. And they are sustainable, enabling farmers to earn a profit and continue in the seed production and delivery business.

These enterprises are established through multi-stakeholder processes involving different institutions and are provided with key facilities and equipment (e.g., storage facilities and mobile cleaners). Training in the technical aspects of seed production and business management is provided, and they are linked to formal sector institutions (such as research and seed organizations). They are monitored and evaluated for their profitability and sustainability, and are linked in networks at provincial levels that facilitate the flow of information (especially about markets) Several VBSEs have been established and are operational on an individual/group basis, and are dealing with a range of crops in the CWANA region. The approach fits well with participatory variety selection and participatory plant breeding.
2014

- Performance of alternative seed delivery models is monitored
- Sustainability and functionality of alternative systems are monitored and validated
- Functional seed units are operational within NARES structure in at least five countries
- Sub-regions are identified for potential regional harmonization in the seed sector (e.g., East and North Africa, etc.)
- On-going rationalization and harmonization efforts in different sub-regions (e.g. COMESA, ECOWAS, SADC, ECO, etc.) receive technical support

Output 1.7 **Strengthened knowledge and capacity of partners and smallholder farmers to sustainably increase the production of dryland cereals**

To facilitate farm-level impacts, DRYLAND CEREALS needs to ensure that new insights are effectively communicated to target clients – smallholder farmers, both women and men – in appropriate ways. New information technologies are rapidly becoming more available in rural areas, even those where dryland cereals prevail. Thus, new opportunities for providing useful and timely information, even to remote farmers, are need to be harnessed. Based on experience gained from implementing farmer field schools on specific topics, messages and tools will be refined for large-scale delivery through rural radio stations (in partnership with Farm Radio International), rural film-based discussion sessions, and possibly cell phone-based messaging or information centers.

Building research capacity is an integral part of all previously described research activities, especially in view of the aging of NARES staff and infrastructure across Sub-Saharan Africa. To coordinate these efforts, and maintain an entry point for collaboration with specific programs on researcher training, we will implemented/or facilitate the training needed to achieve success with the dryland cereals.

**Activities**

- Assessment of capacity strengthening and infrastructure refurbishment needs of partners and stakeholders along the impact pathway;
- Provide tools and resources for partners to access, analyze and document data generated through the CRP and companion initiatives
- Prioritization and provision of capacity strengthening (e.g., farmer field schools, degree training, gender analysis) and refurbishment of infrastructure for partners;
- Organization of sensitization workshops on gender issues for all partners;
- Enhanced communication tools for facilitating adoption and adaptation of newly created integrated technologies by farmers on a large scale;
- Stimulate the development of social networks around specific thematic or professional expertise; and
- Identify best practices and lessons learned relative to creating and communicating integrated production technologies.

**Key Milestones (2012-2014)**

**2012**

- Needs assessment of capacities of partners established and addressed to allow start-up of marker-based breeding projects
- Publication of well-tested Training Manuals for the implementation of Farmer Field Schools, quality seed production, and participatory variety evaluations
Courses on marker-assisted breeding conducted and Molecular Breeding Community of Practice established
DVD with a series of videos to promote integrated *Striga* and soil fertility management distributed to 100,000 potential users
Programmers of rural radio stations trained in how to promote dryland cereal production
Seed storage facilities for dryland cereal breeding programs in WCA improved

2013
- Gender strategy refined for specific production systems in each target region
- Programmers of rural radio stations trained in promoting nutritional advantages of dryland cereals, as well household processing options for improving bio-availability
- MSc students trained in breeding, agronomy, markets economics and communication science in all DRYLAND CEREALS target regions
- Strategy developed to improve laboratory facilities of NARES partners in Sub-Saharan Africa

2014
- Gender sensitization workshops conducted in at least 2 key target regions
- Participatory radio programming tested for gender- and nutrition-related messages
- PhD awarded to students working on breeding tool for improved adaptation to abiotic and biotic stresses

**STRATEGIC OBJECTIVE 2 – CONTRIBUTING TO ECONOMIC GROWTH BY IMPROVING THE PROFITABILITY OF DRYLAND CEREALS PRODUCTION AND INCREASING MARKETING OPTIONS**

**Vision of Success**
Success for the DRYLAND CEREALS Strategic Objective 2 will be reflected in significant and sustainable increases in the incomes of smallholder farmers through the increased profitability of dryland cereal production. We envision greater market demand for dryland cereal grains and their “leavings” (stover, stalks and straw) for a range of diverse value chains. Farmers will be better able to respond to increased demand by using the improved varieties and production technologies produced through Strategic Objectives 1 and 3. Working with a broader array of partners across a wide range of environmental and socio-cultural conditions will provide insights into market-driven agricultural development under adverse climatic conditions, as well as the operation of dryland cereal value chains.

Farmers in the drylands will have access to new cereal varieties specifically developed with appropriate combinations of food, feed and fodder traits for use in crop-livestock systems, which will increase farmers’ access to markets and income from the sale of grain, feed and fodder. Superior dual-purpose grain-fodder varieties, combined with improved residue management techniques, will create synergies that increase incomes both for mixed crop/livestock farmers and for livestock keepers and their families. Improved fodder quality and quantity will improve the strength/power of draft animals at the time of land preparation and sowing, thus increasing smallholder production and productivity. Improved availability of animal manure would also have a positive impact on soil fertility. Moreover, the use of new, more robust and resilient (stable) dual-purpose dryland cereal varieties will reduce production risks for resource-poor farmers, especially since investments in livestock tend to buffer the large year-to-year variations in biomass production. We expect that national varietal release programs will adopt feed and fodder characteristics as important criteria for releasing a variety, thus encouraging the availability of seed of such varieties.
Feed and fodder traits for improved quality and quantity will be incorporated into on-going national and international dryland cereal improvement programs. National varietal release programs will adopt feed and fodder characteristics as important criteria for new varieties. Improved feed and fodder varieties for smallholder farmers in dryland areas will become more readily available. And farmers will become more knowledgeable about the advantages and uses of improved, dual-purpose dryland cereals in crop/livestock systems. Besides feed and fodder traits, varieties will be developed with specific traits required by industry for various uses, such as processed foods, ethanol, and poultry feed.

Finally, farmers will benefit from emerging opportunities for larger scale commercial grain procurement (through/for/with food security operators like the World Food Programme, malting industries and feed mills). 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.

**Challenges and Opportunities**

Our key challenge, and at the same time our prime opportunity, is that successful market access for smallholder dryland cereal farmers can lead to a quantum change for the better in the well-being and livelihoods for some of the most disadvantaged farm households in the world. While producing farm and community level impacts, we will also be able to document and more fully understand the conditions necessary for such change to take place – and how to replicate them elsewhere at a larger scale.

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.

Achieving success will require action-oriented interdisciplinary collaboration across the Research-for-Development continuum (R4D), from high-throughput genetics labs to seed production fields, from machinery repair workshops and rural radio stations to the offices of company executives and political decision makers. Such interdisciplinary work is challenging to manage and often involves high transaction costs. In a similar vein, there is a need for linkages across CRPs dealing with similar issues re crop production under highly unpredictable conditions and improving market access for smallholder farmers. Moreover, climate change and the already highly unpredictable, variable growing conditions require crop production technologies that are well targeted and enhance stability of production.

Opportunities for increasing market demand for dryland cereals products are many, and are rapidly evolving. Research needs to ensure that smallholder farmers and women can benefit from:

- Improving dry-season feeding options for livestock;
- Developing business opportunities for animal feed, based on higher quality cereal stover and straw;
- Fodder from crop residues that does not require additional water or land, and which thus enhances overall crop value;
- The large genetic diversity for stover and straw quality traits that is available yet underexploited in dryland cereals for the producing dual-purpose types;
- The rapid increase in demand for meat and milk products;
- Investments by large-scale malting industries in acquiring raw materials from local markets, with a view to supporting local farming communities;
• Developing animal feed industries in SAT that are discovering the advantages of locally produced dryland cereals compared to imported feed grains;
• The use of sweet sorghum juice for producing ethanol, or as an alternative sweetener;
• Growing consumer interest in and return to traditional, ethnic foods across Sub-Saharan Africa and among African emigrants overseas;
• The increasing demand for no-gluten cereals;
• The growing demand for locally produced dryland cereals triggered by relatively high prices for rice and wheat; and
• Opportunities to meet the needs of emergency food providers (such as the World Food Programme), which are experimenting with direct procurement from local farmer organizations.

Serious challenges remain, but can be addressed by interdisciplinary R4D. For example:

• Food processing research and the commercial industry it supports are in their infancy in most DRYLAND CEREALS target regions, especially in Sub-Saharan Africa;
• Smallholder farmers are poorly organized and poorly educated and thus require institutional support for engaging with large-volume markets; and
• Credit providers are hesitant to invest in staple food crop production, especially in situations where traditional land use rights predominate.

Dryland cereal seed systems are very diverse, and a major challenge we face is the creation of sustainable linkages between successful crop breeding programs for areas that have not attracted much private sector investment in seed production and marketing. A key issue will be the need for providing quality seed of a high degree of varietal diversity, as well as high rate of varietal change.

The inability of producers in our target regions and countries to feed animals adequately throughout the year remains the major technical constraint in most livestock systems (Ayantunde et al., 2005). Feeding during the dry season is particularly problematic, with animal weight loss and lower productivity resulting from reduced feed quantity and quality. Meeting the predicted future demand for meat and milk (Delgado et al., 1999) in ways that enable rural poor livestock keepers to benefit more from their animal assets will require sustainable inputs of labor, land, water and nutrients to produce the animal feed required.

Besides greenhouse gases, the apparent high water requirement for livestock production is a major concern. In conventional terms, the water needed to raise livestock is gauged by the amount the animals must drink to sustain themselves, but in fact most of the water required for livestock production is consumed through evapotranspiration in producing animal feed. Water use – and more generally, sustainable natural resource use – must be a concern to those who work in feed resource development and livestock nutrition, and it is in these areas that significant challenges and opportunities exist.

Fodder from crop residues such as stover and straw does not require the allocation of additional land and water because they are a “by-product” of the production of grain. This makes crop residues the single most important – and affordable – fodder resource for smallholders in dryland areas. Thus, any improvement in the nutritive value of crop residues, however small, can have considerable value and impact. Although cereal crops residues generally have low nutritive quality, especially from grain types, genetic variation is being exploited to develop dual-purpose types that combine improved stover/straw quality with acceptable grain production.

Output, Activities and Key Milestones
Realizing our vision of success for Strategic Output 2 will require a number of partnerships with NARESs, ARIs, private sector organizations and development partners (as described in the Partnership Section), and with CRPs 1.1, 2, 3.5 and 3.7 (as described in the Interactions with other CRPs Section). To create
conditions conducive to achieve the planned outcome of increased income for smallholder farmers, we have planned research focusing on producing five key outputs. The first focuses on gathering the necessary insights, and in some cases experiences with specific value chain analyses, for targeting long-term collaborative interdisciplinary research on priority regions, markets and products. The monitoring of dryland cereals production statistics, dryland cereals grain and stover/straw markets, prices, as well as input use statistics, together with the maintenance of monitoring data sets for specific projects, case studies will assist setting priorities between crops, regions, markets and approaches. These data will also support priority-setting needs for Strategic Objectives 1 and 3.

The other four outputs target specific income-generating opportunities, and the necessary research to ensure that 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.

Industrial users, as well as other large-scale buyers of sorghum grain, may have specific quality requirements, e.g., malting qualities, grain color, or texture for their specific processes and needs. Cereal varieties need to combine these traits, with the necessary adaptation and productivity. Most importantly, farmers need to be well organized, so that these industries can buy from them efficiently, i.e., with low transaction costs, for the purchase of reliable quantities that meet agreed quality standards. This requires social and institutional economics research. A growing market opportunity is expected to develop from new food products and preprocessed foods from dryland cereals, targeting largely urban markets. Food processing, as well market research, is necessary to develop these new business opportunities, which could also become income generation options for urban and possibly rural women. Another market opportunity we do not want leave aside are the existing dryland cereal markets for grain or processed products, such as traditional malt markets in some West African countries. Related research will focus on understanding value chain details, and communication tools that can help producers benefit from high seasonal price fluctuations and capture a greater share of the total market value.

Output 2.1  Knowledge and data on dryland cereal value chains related to grain and fodder for livestock, industrial uses, surplus marketing and food processing

Dryland cereals are becoming sources of income for smallholder farmers in various different ways, especially for women. The bottlenecks to enhancing income generation from dryland cereals can be very different and diverse depending on the key actors and markets or uses, the risks involved in crop production, the level of development of the livestock sector, alternative options for cereal cultivation, as well as for fodder production. It is therefore important that detailed analyses of key value chains are conducted, to guide future research and development activities. Thus economic features such as transaction costs, profit margins, etc, are assessed, and thus specifications for quality requirements are identified.

While there is a range of approaches used for such analyses, depending on the scale, the type of stakeholders involved, and the availability of information from existing sources, we expect that in some targeted cases this analysis itself is best conducted with active stakeholder participation from the beginning. Tools or institutional arrangements for conducting such analyses while initiating appropriate action shall be developed and evaluated. As a result of this diagnostic work, strong partnerships between processing industries, farmer representatives, research groups, input suppliers, and other key actors in specific value chains shall be established. For anyone value chain we expect that a shared level of understanding is achieved of key bottlenecks, priority research and development activities identified.
The monitoring of dryland cereals production statistics, dryland cereals grain and stover markets, prices, as well as input use statistics, together with the maintenance of monitoring data sets for specific projects, case studies will assist setting priorities between crops, regions, markets and approaches.

Activities

- Analysis of specific feed/fodder/industrial quality needs for specific priority livestock production systems and value chains;
- Identification of business opportunities for dryland cereal based enterprises and value addition;
- Establishment of institutional and social platforms to identify innovative agro-enterprise options to improve the livelihoods of women and men;
- Creation of awareness of business opportunities related to dryland cereals, with a specific focus on women in order to foster interest by development investors, and policy makers; and
- Provision of evidence-based policy advice that encourages diversification of dryland cereal uses in ways that especially benefit smallholder farmers.

Key Milestones (2012-2014)

2012

- Demand and potential value chains mapped for livestock feed/fodder in specific target regions, considering urban, peri-urban and rural settings
- Identify business opportunities for women in specialty dairy production and processing
- Analysis of policy constraints that limit input/output markets for diversification of dryland cereals

2013

- Economic features and product specifications for value chains for livestock feed and fodder assessed
- Business opportunities for women in enhancing quality and income from traditional cereal malting enterprises assessed
- The development of more efficient fodder markets encouraged in at least two priority production systems
- Identify/select functioning fodder markets with growth potential at representative research sites
- Potentials for specific value chain and business opportunities documented with ex ante impact assessments to guide development investors in at least three specific dryland cereal production contexts
- Facilitate policy changes that contribute to market opportunities to maximize profitability for smallholder farmers

2014

- Value chain options for syrup production by smallholder farmers in South Asia and West Africa assessed
- Opportunities for supporting/engaging with industry-led malting enterprises identified
- Market analyses for urban and regional demand for dryland cereal grain
- Impacts on market efficiency and benefits to producers quantified by determining and analyzing such elements as transport distances, volumes and seasonality of traded straw and stover, the cultivars being used as the sources of these feeds, price/quality ratios, and farm gate prices
Effective innovation platforms developed for future enhancements of specific value chains
Sustainable options for raising grain and/or stover/straw yields determined to achieve reliable production increases by smallholder farmers, especially women
Capacity strengthened to conduct effective value chain analyses considering also the empowerment of women
Capacity strengthened of local partners to raise awareness on income generation opportunities Knowledge-sharing and information exchange platform along the value chain for value added products and markets
Facilitate policy changes that contribute to market opportunities to maximize profitability for smallholder farmers

Output 2.2  Improved dryland cereals with characteristics that support the livestock revolution in marginal environments

We expect as a result of this planned research, that farmers in the drylands will have access to new dryland cereal varieties specifically developed with appropriate combinations of food, feed and fodder traits for use in crop-livestock systems, which will increase farmers access to markets and income from sale of grain, feed and fodder. Feed and fodder quality/quantity traits and genes will be incorporated into on-going dryland cereal improvement programs. National varietal release programs will recognize feed and fodder characteristics as important criteria for new varieties. Improved feed and fodder varieties for smallholder farmers in dryland areas will become more readily available. And farmers will become more knowledgeable about the advantages and uses of dryland cereals in crop/livestock systems.

Activities
- Detection and use of existing germplasm and varietal diversity for feed/fodder/industrial traits in dryland cereals;
- Development of true multipurpose dryland cereals that optimize grain and fodder production under farmers’ growing conditions;
- Assessment of the role of gender as it relates to constraints and opportunities to access and benefit from crop residues and manure;
- Addition of value to dryland cereal crops through stover/straw fortification and densification;
- Development of business models for improved feed manufacturing and marketing (feed blocks, choppers), in collaboration with CRP 3.7.

Key Milestones (2012-2014)
2012
- At least 12 sweet stalk sorghum accessions identified using sorghum mini-core collection (including reference collection) approach
- Identify constraints through focus group meetings, and PRA tools on utilization of crop residues and manure with particular reference to women
- Collection of gender-disaggregated data on roles, responsibilities, access to and control of resources and benefits (main- and by-product) and constraints
- Identify business opportunities for feed production and marketing
NIRS hub established with various NIRS instruments calibrated against a master instrument for all pertinent NIRS equations (CRP 3.7)

Broad based breeding populations with high forage yield potential developed for at least 2 dryland cereals

Validated sorghum stay-green QTLs, conferring improved drought adaptation and/or stover digestibility, transferred into 3 B-lines and 3 open-pollinated varieties (OPVs)

Identification of gender-related indicators to reduce gender-based constraints

Feed processing and transport costs established for sorghum and pearl millet stover-based diets;

Assess/analyze business opportunities to enhance income from feed markets

Relationship between grain and stover yield heterosis and genetic diversity of parental germplasm assessed

Cultivars with superior grain yield, crop residue yield, sugar yield and fodder quality identified and promoted

Dual-purpose stay-green and foliar disease resistant dryland cereal varieties and hybrids developed

Multi-cut (single culm/tillering) cultivars developed in a range of maturity groups

High biomass sweet sorghum lines introgressed with low lignin $bmr$ genes

Identification of effective strategies for reaching both men and women and ensuring access and use of new innovations (information, technologies and institutional arrangements) to benefit from crop residues and manure

Livestock performance response to processed improved sorghum and pearl millet stover based diets determined

Facilitate engagement with commercial livestock production

Output 2.3 Efficient dryland cereal production technologies to ensure that farmers can successfully engage with large-scale, industrial processors for a range of alternative end uses

Besides food and fodder, dryland cereals can be used industrially, such as for malting, for ethanol production, for specific flour or feed mixes, as well as for syrup production, which in itself has a range of different end uses. All these uses represent growing markets, within some key target countries and regions of dryland cereal cultivation. Smallholder farmers, especially women, do not benefit from such market opportunities, unless specifically targeted measures are taken. One big hurdle is the organizational challenge for industries to deal with very many smallholder farmers to purchase large quantities of uniform grain. Organizing farmers for such production and delivery offers opportunities to link smallholder farmers also to inputs markets, such as access to credit for the purchase of fertilizers, quality seeds as well as agricultural equipment. This is thus one key avenue to provide smallholder farmers with the urgently required inputs and investments for increasing productivity. If appropriate production technologies are available, this will lead to significant increases in total production, and reduced unit costs of production. The key technologies required are cereal varieties with the desired quality traits for the targeted process; crop management tools for efficient and sustainable increases of productivity, harvest and post harvest technology to assure quality products, and efficient use of the available labor. The basis for achieving this complex output in any specific context is broad-based
stakeholder collaboration and interdisciplinary research to facilitate innovation in the various domains in a targeted manner.

**Activities**

- Development of tools and methods for analysis of specific quality-associated traits;
- Development of varieties and hybrids with industrial quality traits and adaptation to the targeted growing conditions;
- Identification of integrated crop management technologies that reduce smallholder farmer production costs, enhancing competitiveness of dryland cereals in industrial markets;
- Development and evaluation of models for smallholder farmers to produce and market large volumes for industrial uses; and
- Dissemination of evidence-based policy advice that encourages diversification of dryland cereal uses in ways that especially benefit smallholder farmers.

**Collaborative Effort Produces Smallholder-Friendly Pearl Millet Hybrid Population**

The advantages of R4D partnerships are clear in this story of collaboration between a development project funded by IFAD (the Project for the Promotion of Local Agricultural Initiatives – PPILDA), a national research organization (the National Agricultural Research Institute of Niger – INRAN) and an international research center (ICRISAT). PPILDA ensured close contact with smallholder farmers in Niger and facilitated participative evaluation under farmers’ conditions. INRAN carried out testing and put a junior breeder into the field to work on the project. And ICRISAT brought to the table its international research capabilities and key equipment needed for the work.

As part of a crossing scheme between genetically distant pearl millet populations, a Niger pearl millet landrace (*Tiouma*) was crossed in 2006 with an improved variety from Senegal (*Souna3*). The resulting hybrid population performed well at a number of Sahelian testing sites, including the research stations of INRAN (at Maradi) and ICRISAT (at Sadoré). Strong hybrid vigor resulted from crossing parental populations of distinct geographical and genetic origins.

In trials conducted by farmers in the Aguié region of Niger in 2007, the yield of Tiouma x Souna3 was notably better than that of the local traditional (control) cultivar, and the hybrid was rated highly by farmers for its good seedling emergence, tillering, earliness, and very compact panicles. It also received top marks in culinary tests that complemented the field evaluations. Experimentation with the hybrid was done on a larger scale in 2008, where it produced an average yield of 1013 kg/ha (~28% more than the local variety).

Since then, the new hybrid population has gone through additional cycles of multi-location recurrent full-sib family selection to further improve performance, yield stability and resistance to downy mildew. Its release as a new, smallholder-preferred variety in Niger and the Sahelian region of WCA is anticipated in 2011.

Under DRYLAND CEREALS, pearl millet development will build on the hybrid vigor identified in earlier research, and multi-stakeholder partnerships will help expedite farmer adoption and the impact of new cultivars.

**Key Milestones (2012-2014)**

**2012**

- Industry lab, and or food technology labs for grain quality analysis (malting, starch) identified for at least two target zones
- Analysis of policy constraints that limit input/output markets for commercialization of dryland cereals by small holder farmers

**2013**

- Identify cereal varieties and hybrids with specific industrial quality traits, and adaptation for crop ecologies targeted by industries for sourcing grain or stover/straw
➢ Productivity in farmers fields associated with the program achieved regularly grain of more than 2 t/ha
➢ Analyze and predict market demands for at least 3 specific crops or their products, including cereal-fed livestock and poultry in at least 2 different regions each
➢ Effective communication tools developed to facilitate farmer learning for sustainable productivity increase and effective dryland cereal marketing in at least 3 value chains
➢ Communicate the potential of dryland cereal hybrids to public and private investors, (including seed industries) as key opportunities for investments in dryland cereals in at least value chains
➢ Facilitate policy changes that contribute to market opportunities to maximize profitability for smallholder farmers

2014
➢ Screening protocol for target quality traits developed
➢ Develop institutional capacity among dryland cereal partners for effective gender specific (youth and women) change for raising incomes (effective producer marketing groups, farmer managed seed enterprises, managing effective innovation platforms) in at least 3 countries
➢ Facilitate policy changes that contribute to market opportunities to maximize profitability for smallholder farmers

Output 2.4 Improved and innovative post-harvest and food processing technologies for promoting the dryland cereals among traditional users, urban populations and food processing industries

The use of dryland cereals needs to be promoted among the traditional users and potential new users especially the health conscious urban population either for direct consumption or through consumption as value-added food products. Traditional users, especially women, need to be provided with technologies that reduce the drudgery associated with processing of the grains prior to preparation of food. In addition, studies of urban consumption trends for staple food crops in countries where dryland cereals are traditional food crops have shown that dryland cereal consumption is constrained by the amount of time required for cleaning of the grain and food preparation. The lack of commercial value added products from dryland cereals, in spite of their documented health benefits, can be attributed to lack of focused research and development to provide suitable raw materials based on dryland cereals that can be used by the food industry. 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 Objective 3. In summary, to increase overall demand for the dryland cereals from these urban markets, it is thus essential to explore appropriate existing grain processing technologies and equipment and if required develop specific processing machinery and processes. Finally, appropriate business models for transfer and acquisition of these technologies and processes needs to be developed to promote their sustainable use by women and the local food industry. Research is also required into the local value and processing chains for urban use of the dryland cereals, including the purchasing and processing behavior of poor urban households.

It is also essential to develop value-added processed packaged food products from the dryland cereals, for large-scale marketing in urban areas. 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 Objective 3, 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. Crop research needs to work closely with
food science and technology experts in order to develop varieties producing grains with the desired nutritional and functional qualities for food processing operations. Appropriate strategy and business models need to be developed for marketing and promotion of these newly developed food products with the food industry. Special attention needs to be given to develop suitable value chains for providing quality and consistent supply of grains to the food industry at a competitive cost. Such research and business activity is long-term in nature, and requires collaboration with the academia and the private sector in various domains.

Activities

- Identification and adaptation of equipment that reduces drudgery for household processing and business models for their accessibility for rural and urban settings;
- Development of processing technologies for new food products targeting urban markets;
- Upgrading the attractiveness of products from dryland cereals to increase demand;
- Enabling access to appropriate food processing machinery to produce new products efficiently and profitably; and
- Development of varieties with better food processing qualities and adaptation to target growing condition.

Key Milestones (2012-2014)

2012

- Establishment of business models for self-help groups to promote investments in dryland cereal processing technologies at household and community scales
- At least two novel food products, or snack-foods from dryland cereals identified based on their feasibility for processing and marketing in urban areas in two countries, where dryland cereals are well known
- Business models for specific acquisition of food processing machineries established and disseminated in at least two countries
- Options for successful large-scale marketing of pre-processed traditional foods based on dryland cereals, competitive for rice for cooking time, and price
- At least two business incubators for food processing enterprises focusing on dryland cereal products functional in at least two countries
Local capacities for servicing, maintenance and possibly local manufacturing of food processing machinery facilitated in at least two countries

2014

- Training modules for local maintenance and servicing of post-harvest processing machineries adapted for use in village level, and poorer urban settings in at least three countries/crop or type of machinery cases
- At least two health foods based on dryland cereals for non-traditional dryland cereal areas and users identified
- At least two feasibility studies done in collaboration with Strategic Objective 3 on the commercialization of dryland cereals as health foods in non-traditional areas conducted, also to assess their export potential
- Varieties identified with preferred food processing traits and adaptation to the specific target ecology

**Output 2.5  Improved dryland cereal technologies for surplus production and models for strengthening market linkages**

Producing surplus grain for marketing in the absence of such organized markets (such as industrial demand) is at present the most important source of income from dryland cereal grain for small holder farmers. In production systems where dryland cereals are staple food crops, farmers tend to sell these grains only when they are have urgent cash requirements. Research to develop innovations that improve farmers’ chances to derive benefit from these markets will impact a very large number of producers. This research is 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 Objective 1, 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.

**Activities**

- Identification of the genetic basis and development of tools and capacity for improving dryland cereal productivity with improved storability;
- Development of crop management options and understanding of their physiological basis to increase productivity, reduce production costs and enhance storability and product quality;
- Development of opportunities to enhance smallholder farmers’ access to inputs and machinery, through improved communication and availability of credit;
- Development of options for sustainable seed delivery for dryland cereals; and
- Dissemination of evidence-based policy advice that encourages input delivery, and market integration for smallholder dryland cereal producers.

**Key Milestones (2012-2014)**

2012

- Market predictions/forecast provided for specific varietal qualities, to guide breeders and seed producers for at least 4 different dryland cereal value chains
- Best-bet packages of practices for surplus production of dryland cereals identified for at least 2 production systems
Tools for effective recurrent selection in broad-based populations for improving multiple traits (including processing traits) made available to partners for at least two crops

Data management tools for genetic, phenotypic and environmental information to facilitate more efficient multi-trait selection (including qualities for marketing) and learning across crops and production ecologies

Appropriate harvesting procedures and post harvest management guidelines developed to meet market and consumer demands for grain and stover/straw quality

Provide tools for training and support of smallholder farmers for family focused economic analysis of crop management options in at least 4 target countries

Facilitate policy changes that contribute to making market information available to smallholder farmers

Dryland cereal grain marketing channels and bottlenecks for full participation of smallholder farmers identified for at least 3 target 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/straw) and marketable grain quality in drought prone environments

Strengthen facilitation skills in at least 4 dryland cereal teams for creating and maintaining innovation platforms for dryland cereal development, in at least 3 countries

Effective seed marketing and distribution channels network developed for dryland cereals in target regions (WCA, CWANA)

Farmer managed and owned seed production and marketing units developed and operational

Training in technical and business management for emerging small-scale private seed enterprises and grain marketing cooperatives conducted in at least 3 production systems

Facilitate policy changes that contribute to making market information available to smallholder farmers

2014

Dryland cereal hybrids identified for at least two production ecologies, for which hybrids were previously not available, which correspond to industry/market requirements for grain, stalk traits, farmers’ needs and preferences (women and men), and have a clear productivity and cost advantage over existing varieties

Guidelines developed for appropriate storage methods designed

Models for linking farmer groups to credit institutions, input and information providers evaluated

Tools developed for capacity building to use the machineries in crop production and post harvesting

**Strategic Objective 3 – Optimizing Nutritional Value of Dryland Cereals for Better Health**

**Vision of success**

Our vision for success is making a contribution towards the reduction of malnutrition in the drylands, especially among women and children, through greater access and use of nutritionally enhanced dryland cereals. This will be achieved by integrating nutritionally enhanced germplasm and technologies that enhance the nutritional value of dryland cereals in delivery systems developed in Strategic Objectives 1 and 2. Strengthening capacity, knowledge sharing, and awareness raising of stakeholders will be used to mainstream the health value of dryland cereals. Results from this strategic objective will help generate
support for nutrition-related R4D activities, as well as augmenting crop production technologies that will lead to increased production and more profitable smallholder farms.

**Challenges and opportunities**

Strategic Objective 3 provides a number of opportunities through the unique partnership between advanced institutions, leading national programs and CGIAR Centers. These include:

- Platform of partners, in linkage with CRP4 that connects activities of this CRP with a more holistic approach to address issues related to Agriculture, Health and Nutrition;
- Address key nutritional issues from a value chain perspective;
- Mainstreaming traits for nutritional value in dryland cereal improvement programs;
- Assessing the genotypic differences for micronutrients content, processing and storage characteristics;
- Developing low-cost, rapid screening techniques for assessing grain micronutrient content and grain processing quality;
- Developing improved cultivars with enhanced nutritional value;
- Identifying improved cultivars for various quality processed products;
- Understanding the genetic basis for variation in nutritional value (micronutrients, anti-nutritional factors), processing and storage characteristics;
- Establishing the nutrient status of the on-farm sites and assessing the nutritional value of dryland cereals under exogenous crop management schemes;
- Processing technologies identified to reduce the ill effects of phytate and fuminosins and to retain micronutrient content in the processed product;
- Processing technologies identified to increase the shelf-life of the processed products; and
- Assessing the trade-off between investment in enhancing nutritional value of cereal crops and supply through vegetables or other alternatives.

Of course, a number of challenges remain and will be addressed through the opportunities outlined above. Such challenges include:

- Policy advocacy to sensitize policymakers on the importance of the nutritional value of dryland crops;
- Providing evidenced based recommendations to policy makers that will not only sensitize them on the nutritional value of dryland cereals but also create a favorable policy environment for the promotion of nutritionally rich dryland cereal products;
- Involving all stakeholders particularly the processing industry in the private / cooperative sector, civil societies, international agencies as partners in the research agenda for their buy-in and scaling up of nutritionally rich products from dryland cereals;
- Setting up optimal institutional arrangements to speed up effective technology delivery at lower cost; and
- Enhancing women’s education and capacity to enhance nutritional outcomes.

**Outputs, Activities and Key Milestones**

In order to realize our vision of success for Strategic Output 3, we will require a number of partnerships with NARESs, ARIs, private sector organizations and development partners (as described in the Partnership Section), and with CRPs 2 and 4 (as described in the Interactions with other CRPs Section). We will focus on producing five major outputs: knowledge on dietary patterns, malnutrition, processing, and food safety as well as constraints, opportunities and drivers, and entry points; dryland cereal
germplasm with better nutritional value, processing and storage characteristics; diversified and improved strategies, tools and crop management practices to enhance nutritional value, food safety and post-harvest processing; strengthened capacity, knowledge, and awareness of stakeholders to better develop, promote, and disseminate nutritionally enhanced dryland cereals with better processing and storage characteristics; and evidence-based policy and regulatory advice that fosters the production and consumption of safe and nutritious crops by smallholder farmers.

Output 3.1 Knowledge on dietary patterns and malnutrition to identify key constraints and priority opportunities for enhancing nutrition for people dependent on dryland cereals

Understanding the dietary, cultural, and food processing context for people that depend on dryland cereals is critical for identifying the key constraints and opportunities to enhancing nutrition. Improving diets must include not only overcoming resource limitations, but targeting those resources to those with greatest need, enabling better use of those resources through “value-addition”, processing and food preparation techniques, and enabling change in consumption behavior through better understanding of nutrition. The trade-off between cost and nutritional benefits both at a household and macro level and information on cultural aspects of food consumption at household level will be valuable in designing nutrition programs and policies to overcome malnutrition among the vulnerable sections of population dependent on dryland cereals. This component of DRYLAND CEREALS aligns closely with targeting components of CRP4 that focus on nutrition-associated value chains. To avoid overlap and enhance synergy, we have identified specific and unique aspects to be carried out in the scope of DRYLAND CEREALS.

Activities

- Conducting and compiling food consumption surveys to assess inter- and intra-household dietary patterns and needs, and the nutritional role of dryland cereals, especially for women and for children 1-5 years of age, for targeted communities dependent on dryland cereals;
- Identification of key knowledge and resource constraints or opportunities for realizing dryland cereal nutritional benefits; and
- Assessing market demand for more nutritious and/or safe dryland cereal food products, and potential new markets assessed with attention to facilitating the access of resource-poor farmers and women in particular;
- Studying gender-based differences in nutritional needs vs. nutritional habits.

Key milestones (2012-2014)

2012

- Food consumption survey for two sorghum production areas in Mali published

2013

- Evidence from household nutrition surveys in key dryland cereal consuming regions generated and shared with scientists, partners and stakeholders
- Surveys of processors and processing methods to identify constraints and opportunities for the development of nutritionally enhanced products

2014

- Opportunities for efficient impact pathways identified for improving child nutrition in rural households growing and consuming dryland cereals
Genetic diversity and the ability to reliably assess it are the foundations for making genetic improvements through crop breeding. Research on dryland cereals indicates the existence of important diversity for grain micronutrient and phytate content as well as flour shelf life (Chugh and Kumar, 2004; Grando, 2005; Rai et al., 2008). However, our own knowledge is incomplete. Thus, this research objective will focus on activities to more effectively utilize such diversity through systematic efforts to understand that diversity, determine effective and efficient methods for screening large numbers of progenies, and finally “whole-plant” breeding to assure combination of nutritional and quality traits with the adaptive and agronomic traits required for successful adoption.

Utilization of dryland cereals can be increased by various processing treatments including blanching, malting, dry heating, acid treatment, and popping. All these treatments decrease the level of anti-nutrients, improve digestibility and increase shelf life. Pearl millet and sorghum can be utilized for development of various food products. These include, traditional products (porridges, flat breads, chips, bhakri, suhali, kichri, dalia, etc.), baked products, extruded products, health products, and weaning and supplementary foods.

Thus, this research objective will also address the interrelationship of processing and product development with grain endosperm and pericarp traits and also their effects on shelf life of various processed and prepared products. Also, the effects of processing traits on the phytate and other micronutrient contents will be studied to improve the processing quality of these grains (Sehgal et al., 2003).

Activities

- Evaluation of genetic resources (including genetic stocks, breeding lines, commercial cultivars) for variation in nutritional value traits, processing, and shelf-life and understanding the genetic basis of this variation;
- Identification and validation of rapid, cost-effective, screening protocols for nutritional and processing traits for large scale variety/progeny evaluations;

Developing Pearl Millet for Asia

Partnership-based R4D has increasingly become ICRISAT’s normal mode of operation in the development of pearl millet. The goal of this work is to capitalize on the comparative and complimentary skills and resources of partners, and to generate rapid and large-scale impact by building on the inherent synergies of those involved. Thus, in the Asia region, ICRISAT conducts strategic research, and develops improved breeding lines and hybrid parents, which are then used by both public and private sector organizations for hybrid development.

This approach is proving very successful, and ICRISAT-bred parental lines are being extensively used in hybrid development. For instance, of the 18 public sector hybrids released in India during the past 10 years, 14 (i.e. 77%) were based on ICRISAT-bred male-sterile lines (Khairwal et al. 2009), and of the 39 public sector hybrids evaluated in the All India Trial in 2008, 27 (i.e. 69%) were based on ICRISAT-bred male-sterile lines. The Indian Council of Agricultural Research recognized the significance of this partnership by conferring the Chaudhary Devi Lal Outstanding Award for coordinated research projects to the team of pearl millet scientists from NARESs and ICRISAT.

Private sector organizations have benefited even more from ICRISAT-bred material. A survey conducted in 2006 found that of the more than 82 hybrids marketed by private seed companies in India (which are now cultivated on more than 4 million hectares), at least 60 (about 75%) are based on ICRISAT-bred male-sterile lines, or on proprietary male-sterile lines developed from ICRISAT-bred materials (Mula et al. 2007). In recognition of this contribution, the Seed Association of India Award was given to ICRISAT’s pearl millet program in 2003.

This fruitful partnership with private seed companies, which was initiated in 2000, provided the basis for an R4D consortium framework that has evolved over time. Twenty seed companies now providing partial funding for pearl millet hybrid parent research. Besides providing funding, consortium seed companies also provide feedback to ICRISAT on farmer preferences regarding plant and grain traits, and they participate in impact assessments. In 2009, this partnership with NARESs and the private sector was further strengthened with five SAUs and nine consortium seed companies undertaking collaborative research to accelerate the development and deployment of bio-fortified hybrids.

Output 3.2  Dryland cereal germplasm and improved breeding lines, hybrid parents and varieties with better nutritional value and processing characteristics
- Development of genetic stocks, breeding populations, and advanced breeding products with enhanced nutritional value, and processing characteristics;
- Documentation of gender differentiated indigenous knowledge and assessing its potential integration in dryland cereal crop improvement; and
- Production of breeders’ seed and identification of seed delivery options that can ensure that farmers know that they are growing a biofortified/nutritionally enhanced variety.

**Key milestones (2012-2014)**

**2012**
- Evaluation of the precision and reliability of a cost-effective tool (XRF) for Fe and Zn analysis for dryland cereals completed and documented
- At least two commercial cultivars of each crop with high iron (>50 ppm in pearl millet and >40 ppm in barley and sorghum) and high Zn (>40 ppm in barley and pearl millet and >30 ppm in sorghum) contents identified for large-scale adoption as bio-fortified cultivars
- Barley, pearl millet and sorghum varieties with increased Fe and Zn concentrations released, and breeders’ seed produced

**2013**
- Validated micronutrient-dense germplasm sources/breeding lines in sorghum (>5 lines with >60 ppm grain Fe and >40 ppm Zn contents) and pearl millet (>10 lines with >80ppm Fe and >60 ppm Zn contents) and barley (5 lines with >50 ppm Fe and >40 ppm Zn) identified
- At least two cultivars each of sorghum and pearl millet with high starch content identified for pharmaceutical and other industrial sector
- Information on variability for characters linked to improved shelf life
- Information generated for characters linked to increase feed quality
- Pearl millet MAGIC population(s) produced suitable for coarse mapping of grain micronutrients (Fe and Zn) density QTLs/genes
- Biofortified version of two high-Fe commercial OPVs with 10-15% higher Fe content developed in pearl millet
- QTLs for Fe and Zn identified and validate in barley
- Methodology for screening sorghum for food relevant Fe and Zn concentration published

**2014**
- More than 10 hybrid parents and at least 3 hybrids with >60 ppm Fe and >40 ppm Zn contents combined with high yield potential and DM resistance developed in pearl millet
- At least 10 barley lines combine high Fe and Zn with high yield developed
- Number of improved cultivars released/commercialized
- Enhanced commercialization of these crops
- At least 4 accessions of sorghum and pearl millet identified with appropriate nutritional and functional properties (diastatic activity, germinating power, water solubility index, water absorption index, water holding capacity, oil absorption capacity, thermal and pasting properties etc.) for identified food industry usage
- Information on genetics, single plant efficiency, and character association of grain Fe and Zn contents in sorghum and pearl millet generated
- QTLs for Fe and Zn identified and validated in pearl millet
At least 2 pipelines hybrids of pearl millet from the national system advanced trials with >50 ppm Fe and >40 ppm Zn identified for possible release

**Output 3.3 Diversified and improved strategies, tools, and crop management practices to enhance nutritional value, food safety, and post-harvest processing**

Smallholder farmers producing dryland cereals use predominantly low-input systems and cultivate in old- (highly weathered), nutrient-poor soils. Thus, growing high-yielding cultivars with micronutrient fertilization may provide an attractive and immediate approach to improve grain-micronutrient content (Johnson et al. 2005). Therefore, this research objective will address the consequences of improved fertility management on micronutrient content, phytate/micronutrient balance, and yields as a vital component for enhancing “micro-nutrient yields”. In this research objective, the interactions between varieties and environments for micronutrient contents will be investigated to identify potential synergies and improve targeting.

Thus, this research objective will also address the interrelationship of processing and product development with grain endosperm and pericarp traits and also their effects on shelf life of various processed and prepared products. Also, the effects of processing traits on the phytate and other micronutrient contents will be studied to improve the processing quality of these grains (Sehgal et al., 2003).

Processing can reduce the ill effects of anti-nutritional factors and increase the shelf life for commercialization. For example, sorghum flour is traditionally known to have reasonable level of shelf life up to 2 months where as pearl millet for 5-6 days at house hold level. This is a major barrier in the commercialization of sorghum and pearl millet flour based products. Recently, it was reported that moist heating of the grain followed by drying to about 10-12% moisture and decortication increases the shelf-life of pearl millet flour for about 3-4 months and sorghum by 8-10 months which needs to be validated and popularized for commercialization (Sehgal et al 2003). In this research objective, the interaction between processing methods and crop management practices will also be evaluated.

**Activities**

- Identification of crop management options (i.e. effect of phosphorus and micronutrient fertilization on phytate, Fe and Zn content) to optimize nutritional value and yields of dryland cereals;
- Identification of post-harvest technologies, processing and food preparation methods that maintain the nutritional value and reduce anti-nutritional factors involving women and respecting cultural appropriateness;
- Development and dissemination of new strategies and tools for mycotoxin management in dryland cereals; and
- Assessment of the magnitude of potential nutrition benefits and socio-economic feasibility of most promising management techniques.

**Key milestones (2012-2014)**

**2012**

- Effect of terminal drought and dwarfing gene on Fe/Zn content in pearl millet documented

**2013**

- Effect of soil/foliar micronutrient application on grain Fe and Zn contents assessed in sorghum and pearl millet
Activities

- Effect of phosphorus fertilization of high Fe/Zn sorghums when grown in highly P-deficient soils on bioavailability of micronutrients documented
- Number of refined processing technologies made available
- Number of new technologies developed to manage phytate and fumonisins
- At least 2 sorghum-based value added food products each of sorghum and pearl millet developed, involving formulation optimization, and nutritional profiling profile to obtain optimized formulations with respect to the processing technology to be used
- Effect of at least two promising processing technologies on the shelf life of flours, in vitro nutritive value of at least two major food products and bioavailability of Fe quantified
- Toxigenic strains of fusarium associated with sorghum grain mold complex characterized

2014

- Acceptability of hand-operated grinder assessed for producing weaning foods with improved concentration of bio-available iron from sorghum, in Mali
- Packaging technologies and labeling protocols developed for commercialization of sorghum and pearl millet food products
- At least 5 sorghum lines resistant to toxigenic strains of fusarium identified
- Study on options for increasing high Fe/Zn cereal production in women’s fields in WCA published

Output 3.4  
**Strengthened capacity, knowledge, and awareness of stakeholders to better develop, promote, and disseminate nutritionally enhanced dryland cereals with better processing and storage characteristics**

Capacity strengthening is a crucial element of the program strengthening and applied research orientation of this component. Achieving the component’s goals requires working with capable partners (individuals and organizations) and effective networks of complementary organizations to multiply efforts. Capacity development will be particularly important for program scale-up and sustainability. This component of DRYLAND CEREALS aligns closely with capacity strengthening components of CRP 4. To avoid overlap and enhance synergy, we have identified specific and unique aspects to be carried out in the scope of DRYLAND CEREALS. Overall, this objective should provide complementary training.

Creating situations where mothers of young children can prepare baby foods with improved micronutrient concentrations requires understanding of which food sources mothers can access, what options for their improvement are available, and how the knowledge and capacity of the mother can be improved. Ensuring that grain of biofortified varieties actually reaches the young children and other vulnerable persons requires close cooperation between health and agricultural development workers. Focus solely on the use of improved cereal grain may not be sufficient, general education about food and nutrition, as well as crop diversification, may be required to achieve sustainable, satisfactory health conditions.

Activities

- Strengthening the capacity of stakeholders to promote and disseminate nutritionally enhanced dryland cereal technologies, especially for consumption by children and women (identifying, documenting, developing and validating impact pathways);
- Identifying and validating impact pathways for improving micronutrient status of young children, who depend on a cereal based diet;
- Developing information modules on nutrition (nature/consequences of micronutrient deficiencies; who is at risk, benefits of improved nutrition), improved technologies (bio-fortified...
varieties, processing/food preparation, crop management), and capacity strengthening of stakeholders to enhance nutritional value of dryland cereals for smallholder farmers;

- Providing knowledge sharing tools and protocols as IPGs that target information on the nutritional value of dryland cereals to stakeholders with an emphasis on methodologies for effective ways of communication (which media, social/institutional context etc.) and targeting; and
- Raising the awareness among women and men about 1) best strategies to adopt a nutritious diet in the household; 2) methods to improve food storage; 3) alternative food products; and 4) intra-household food distribution issues.

**Key milestones (2012-2014)**

**2012**

- A consortium of self help groups involved in activities at the household and community level established to promote value-added food products
- Gender-specific interventions introduced to promote value-added food products making best use of individual and existing networks
- Identification of pilot learning site in each cluster/region for introduction of gender-specific interventions to promote value-added food products making best use of individual and existing networks; provide methods and study the facilitation of learning across different sites

**2013**

- A workshop on developing linkages among various sectors (farmers, food manufacturers, process equipment designers and equipment manufacturers and marketing agencies) on seed/grain production and food products development/processing/delivery chain held and proceedings published
- At least 2 training programs conducted to promote value-added food products at the household and community level involving the self-help group consortium members

**2014**

- Nutritional and nutraceutical evaluation for in vitro evaluation including (bioactivity, bioavailability, and digestibility)
- Studies on at least two hybrids/cultivars each of sorghum- and pearl millet-based value-added food products completed and their safety and commercial impact established
- Social capital and social networks (e.g., self-help groups for women, farmer’s associations and groups for men and women, etc.) built based on the lessons learned in years 1 and 2 to empower men, women, youth and the community at large

**Output 3.5 Evidence-based policy and regulatory advice that fosters the production and consumption of safe and nutritious crops by smallholder farmers**

This component of DRYLAND CEREALS aligns closely with policy components of CRP4. To avoid overlap and enhance synergy, we have identified specific and unique aspects to be carried out in the scope of DRYLAND CEREALS (Appendix XX). Thus, this research objective will focus on complementary rather than duplicative activities.

**Activities**

- Reviewing and analyzing agriculturally-related policies affecting malnutrition and food safety of dryland cereals;
Publishing ex ante impact analysis of promising technologies management practices to combat smallholder household malnutrition and improve food safety of dryland cereals;

Publishing evidence-based policy briefs and advocate policy and institutional changes required to reduce malnutrition and increase food safety of dryland cereals in smallholder farm households, as well as for the urban poor;

Providing evidence of accessibility, suitability, and socioeconomic risks of adopting new nutritionally enhanced varieties using gender and social analysis integrated in ex ante, monitoring and evaluation and ex post assessments; and

Evaluating the impact of seed policies and regulations at ground level from a gender perspective.

Key milestones (2012-2014)

2012

- Ex ante impact assessment of bio-fortified pearl millet varieties for South Asia documented

2013

- Review of nutrition relevant agricultural policies in at least one target region
- Monitoring framework for nutrition related impacts of dryland cereal research for development developed with a broad range of partners, and key stakeholders

2014

- Study designed with stakeholders to assess the impact of seed policies and regulations on the availability of biofortified cereal varieties

PARTNERS (INTERNATIONAL, NATIONAL AND REGIONAL)

The initial R4D partners in DRYLAND CEREALS (ICRISAT, ICARDA, the Generation Challenge Program, ICAR, IRD, CIRAD, INTSORMIL – see Appendix 2 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 5). 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 6) 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 wide array of both traditional and entirely new partnerships is 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; Advanced Research Institutions 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 farmers and well-established farmers’ associations in key locations (see Table 5).
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 extended 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.

**Partnerships for achieving Strategic Objective 1**

The partners involved in DRYLAND CEREALS have a long history of breeding for abiotic and biotic stress tolerance for dryland agriculture. Crop-specific or center-specific successes have been achieved and each partner network has had a substantial impact at the research and farm levels. Significant efforts, especially those supported by the Generation Challenge Program, have been made by individual centers in partnership with ARIs and NARES to characterize and begin exploiting the untapped genetic variability present in collections for different crops. Undoubtedly, these successes and achievements will now be extended in scale due the utilization of novel tools.

In order to effectively fuel innovation in dryland cereals, partnerships must be organized in a very strategic manner, and be based primarily on the ability of each potential partner to make significant and timely contributions to the activities in which they are involved. NARES/NGOs that often work with the different CG centers in evaluating new germplasm will be extensively involved in the generation of the
phenotypic database, and the production of agronomic, performance, environmental and market information needed for building a geo-spatial information bank. For the latter, ARIs and the private sector will be called upon to partner with DRYLAND CEREALS and provide the expertise in geospatial modeling. For phenotyping aspects, it will be essential to invest again in human and physical capacity building of partners, to ensure increases in throughput and that phenotypic data are collected uniformly using sound and standardized protocols.

Sequencing technologies are advancing very rapidly and several ARIs and private sector companies can be enlisted to help, within the time frame of this CRP, to generate whole-genome sequence information for most of the dryland crops included here. Universities and agricultural colleges will also be enlisted to contribute agricultural students to work on timely research issues and obtain graduate degrees in exchange. Thus, the overarching premise is that specific partners will be called upon based on their competitive advantage to bring innovation to dryland cereals in a way that complements expertise present in the CG centers/GCP partner network.

A broad range of international, regional, and national organizations with a strong interest in improved dryland cereal varieties and seeds will be key partners in seed system analysis and research. The major research and/or development partners include:

- National agricultural research organizations working on variety development in collaboration with international centers;
- National agricultural extension services working with national partners in promoting improved dryland cereals and associated technologies;
- National seed regulatory agencies dealing with crop varieties, seeds, and phytosanitary measures in ensuring seed quality for commercialization;
- Public seed enterprises and emerging local private seed companies and farmer groups involved in dryland cereals seed production and marketing;
- Regional and national seed trade associations representing the interests of the seed industry in their respective regions and countries;
- Gender experts and practitioners in international and national organizations, such as CGIAR centers, FAO, other UN Agencies, and NGO working on rural development;
- International and national partners, such as FAO, OECD, ISTA, ISF, UPOV, and NGOs, with an interest in agricultural and seed sector development; and
- National agro-industries involved in dryland cereals processing and marketing.

Future success in developing dryland cereal hybrids will rest on developing an array of new, non-traditional partnerships. Local entities, such as well-established and budding 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 (commercial) businesses that need dryland cereals in order to produce products for end users (such as breweries), and service and input providers will all be essential partners for the successful development, distribution and adoption of dryland cereal varieties and hybrids.

Farmers’ organizations are working with others to implement more favorable input supply schemes for their members, and are also becoming more effective in increasing their bargaining power in local, national and regional cereal and seed markets. In addition, agro-retailers are discovering new opportunities for marketing agricultural inputs in areas where dryland cereals are grown. Direct collaboration between these actors and researchers facilitates identification of preferred varieties and other useful production technologies, such as microdosing of fertilizers, for large-scale dissemination.
Collaboration among social and gender specialists will be encouraged through a platform created as part of this CRP. This will facilitate the exchange of best practices and lessons learnt on strategies to achieve food sufficiency in both quantitative and qualitative terms.

Finally, DRYLAND CEREALS will need to partner with many of the other CRPs (see Section on Interactions with Other CRPs) to most effectively produce the outputs proposed and to have the highest achievable impacts.

**Partnerships for achieving Strategic Objective 2**

Close collaboration with national researchers, their institutes and regional coordination bodies will be essential to the successful implementation of Strategic Objective 2. While technology development collaborations will focus on bringing together the necessary competencies for making rapid advances possible, in close coordination with Strategic Objective 1, we will foster functional coordination, as well as collaboration across similar target regions to ensure that an optimum number and mix of partners can access innovations in the shortest possible time.

Partnerships with universities and Advanced Research Institutes will focus on specific innovations, research, and training, as well on complementarities with the specific teams targeting specific value chains and opportunities for improving them. Some of our key partners will be:

- The University of Hohenheim, which has collaborated on improved breeding methodology on all the crops targeted by DRYLAND CEREALS. Similarly, its rural communications department has in the past made significant contributions to the research methodologies used by dryland cereals researchers;
- INTSORMIL, especially on cereal grain processing, crop intensification, as well as entomology and genomics research;
- CIRAD, with its capacities for sorghum genetic research, crop modeling, 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.

DRYLAND CEREALS will seek to increase its interactions with universities in target countries and regions, so as to improve the sustainability of efforts to improve capacity building for dryland cereals research. We will work to create links between southern universities across the continents, as well from North to South.

Private sector companies in the dryland cereal processing sectors, as well as in the seed sector, will be key partners not only for creating targeted research outputs, but also for facilitating large-scale outcomes. Some examples:

- Malting companies (Kenya Breweries, Nigeria Breweries, Assela Malt Factory and Ethiopian Breweries.);
- Industrial grain processors and their supply chain contributors: Unga flour mills, Kenya;
- Aba Malting Plant, Nigeria;
- Hybrid Seed Parent Consortium, India; and
- The World Health Programme’s Purchase for Progress initiative.

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:
• Local entities, such as well-established and budding farmers’ associations, will play critical roles in identifying farmers’ needs and opportunities in specific zones or regions, as well as becoming partners in technology testing;
• Development organizations and NGOs working to improve crop productivity and sustainability in dryland areas, with a capacity for training producers;
• Processing industries and potential large-scale buyers, such as P4P;
• Service and input providers (local banks, extension services, agro-dealerships, and radio stations) will all be important partners;
• Machinery developers and providers, maintenance specialists, to ensure that processing equipment functions correctly and efficiently; and
• Engineering specialists in research, and in agricultural-related manufacturing and agribusinesses.

**Partnerships for achieving Strategic Objective 3**
Partners will play key roles in the identification of improved germplasm, improved protocols for processing and storage traits, indigenous technologies, providing test-sites for multi location evaluation and developing improved cultivars using the improved germplasm and commercialization of the improved products with the help of entrepreneurs. Partners from the health sector will be important during the diagnostic and assessment phases.

In the past 5 years, biofortification research on pearl millet has led to the identification of germplasm, improved breeding lines, and OPVs that have high iron content in the grain, and recent research has identified QTLs for both iron and zinc. In addition, sorghum cultivars with high iron content have been found. These advances resulted from multi-institutional efforts, including the participation of ARIs in India and Australia to assess mineral content. An Australian partner in the biofortification effort has tested a X-ray fluorescence (XRF) device that has been found to provide precise mineral density estimates and can analyze 3-4 times more samples per day than current procedures and do this non-destructively at markedly lower cost.

Business incubators for sorghum and pearl millet food processing are starting up in Mali and Niger, in collaboration of INRAN, and IER, with INTSORMIL (Purdue University) and ICRISAT. They are starting to show their potential, in terms of making high quality intermediate products available for the preparation of traditional food in West Africa. These products are also increasingly finding a market among the West African Diaspora in Europe and North America.

ICARDA, in collaboration with several NARES and ARIs, has conducted research on micronutrient-rich barley has led to the identification of germplasm with high grain iron content. This was possible as a result of multi-institutional efforts, with Australia undertaking mineral analyses at early stage and providing advice on establishing the micronutrient laboratory at ICARDA. In the highland of Ethiopia, malting barley is becoming a good source of income and it can be made a dependable income generating commodity for farmers if a high quality seed supply system is ensured, and breweries offer an attractive price to the producers. There are six breweries currently operating, but only a few use locally produced malting barley. Almost 94% of the local supply of malting barley is from small-scale producers and the remainder is from commercial farms. Encouraging efforts are under way to facilitate domestic malting barley supply (Assefa and Debebe, 2010).

The above descriptions are clear reflections of the power of partnerships – collaborative relationships that have contributed significantly, against difficult odds. Even greater successes in the future are needed and will rest on effective and equal partnerships with a wider array of potential collaborators, including the following:
• Various international agricultural research centers and programs, including ICRISAT, ICARDA, ICAR, INSORTMIL, ILRI, and the GCP to generate a collective force for the importance of dryland cereals for nutrition and health, and to undertake strategic research;

• National Agricultural Research Systems to bring in region-specific expertise and resources;

• Organizations involved in health and nutrition-related issues (i.e. World Food Program and various NGOs);

• Advanced research institutes to provide basic research products that require special expertise and equipment not readily available elsewhere;

• Private seed companies and farmers organizations to undertake hybrid development, seed production and marketing, and provide feedback on varietal performance and farmers’ emerging preferences;

• Other CRPs, including CRP 1.1, CRP 2, CRP7, and in particular CRP 4’s agriculture, nutrition, and health platform;

• Various NGOs for technology delivery, evaluation, and information dissemination;

• Processing and food sector 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;

• 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;

• Traders and wholesalers to market improve seed and new food products;

• Small, medium and large food product outlets; and

• Ministries of Health and Information to provide policy and funding support.
Table 5. Role of partners in DRYLAND CEREALS

<table>
<thead>
<tr>
<th>Output</th>
<th>NARES in Africa &amp; Asia</th>
<th>ARIs</th>
<th>Private Sector</th>
<th>NGOs, CSOs, Farmers Organizations</th>
<th>CGIAR Centers</th>
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<tbody>
<tr>
<td><strong>Strategic Objective 1 - Increasing &amp; sustaining the production of dryland cereals</strong></td>
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<tr>
<td>Output 1.1: Targeting &amp; policies</td>
<td>Conduct data collection for priorities, participate in priority setting, identify policy changes required</td>
<td>Contribute existing databases, based on ongoing and previous project in the target regions Provide crop modeling expertise for scenario analyses (CIRAD)</td>
<td>Remote sensing data, (DigitalGlobe); demand estimates for specific dryland cereal food products (SMEs)</td>
<td>Contribute to data collection, and the identification of priorities for crop improvement research</td>
<td>Facilitate data collection and storage/analysis for priorities, participate in priority setting, identify policy changes required</td>
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<tr>
<td>Output 1.2: Tools &amp; methods</td>
<td>Identify missing genetic resources and conduct collection missions, establish phenotyping facilities and integrated breeding platform, develop genomic tools (especially for finger millet)</td>
<td>Identify missing genetic resources, support the establishment of phenotyping facilities and integrated breeding platforms, develop genomic tools</td>
<td>Capacity strengthening of breeders interested to develop hybrids (Private Seed companies)</td>
<td>Contribute skills and field facilities for variety and germplasm evaluation</td>
<td>Identify missing genetic resources and conduct collection missions, establish phenotyping facilities and integrated breeding platform, develop genomic tools</td>
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<tr>
<td>Output 1.3: Stress tolerant varieties</td>
<td>Conduct breeding of local varieties Sources of Striga resistance Methodological support, and PhD training</td>
<td>Testing sites, feedback from using specific sources of germplasm</td>
<td>Variety evaluations, feedback on usefulness of specific sources of germplasm</td>
<td>Conduct breeding to combine multiple traits into widely-adaptable germplasm</td>
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<tr>
<td>Output 1.4: Dryland cereal hybrids</td>
<td>Determine heterotic pools of local germplasm using genotypic and phenotypic data, conduct breeding of hybrid parents, conduct hybrid trials on-station and on-farm</td>
<td>Methodological support, and PhD training Testing hybrids, develop hybrid seed production protocols</td>
<td>Contribute to hybrid evaluations, and start-up hybrid seed production initiative/cooperatives</td>
<td>Determine heterotic pools of global germplasm using genotypic and phenotypic data, conduct breeding of hybrid parents, conduct hybrid trials on-station</td>
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<tr>
<td>Output 1.5 Crop management options</td>
<td>Conduct on-station and on-farm trials on management options Methodological support, and PhD training</td>
<td>Identify priority options for experimentation, conduct and evaluate on-farm trials,</td>
<td>Identify management options, conduct on-station and on-farm trials on management options</td>
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<td>Output 1.6: Seed &amp; input systems</td>
<td>Support local, community-based and commercial seed system developments, identify appropriate input dealers</td>
<td>Develop seed and input supply options, assist in establishing local seed and input systems, facilitate local private-sector seed systems</td>
<td>Build up capacity for dryland cereal seed distribution, and possibly production</td>
<td>Establish capacity for quality seed production, and linkages o seed markets, local seed distribution systems, linking to traditional informal seed systems</td>
<td>Develop seed and input supply options, assist in establishing local seed and input systems, facilitate local private-sector seed systems</td>
</tr>
<tr>
<td>Output</td>
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<td>Output 1.7: Strengthened knowledge &amp; capacity</td>
<td>Conduct training in crop improvement &amp; management, seed systems</td>
<td>Assist in training in genomics, crop improvement (including marker-assisted) and management, seed systems</td>
<td>Assist with training breeders for product development</td>
<td>Develop capacity for farmer field school facilitation, and develop capacity for working effectively with rural radios, and other media for large-scale communications</td>
<td>Facilitate training in genomics, crop improvement (including marker-assisted) &amp; crop management, seed systems enhancement</td>
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**Strategic Objective 2 - Contributing to economic growth from dryland cereals**

<table>
<thead>
<tr>
<th>Output 2.1: Knowledge &amp; data on value addition</th>
<th>Conduct data collection for priorities, participate in priority setting, identify policy changes required</th>
<th>Provide datasets derived from previous project, insights into new opportunities</th>
<th>Provide insights into quality standards required, delivery and payment options for grain producers,</th>
<th>Share experiences with specific marketing initiatives, demand estimates, quality issues observed</th>
<th>Facilitate data collection and storage/analysis for priorities, participate in priority setting, identify policy changes required</th>
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<tr>
<td>Output 2.2: Dryland cereals for livestock</td>
<td>Conduct breeding of local varieties</td>
<td>Support for improving analytical tools, student training</td>
<td>Investments in fodder and feed sector, South-south collaboration to make fodder processing equipment available in SSA</td>
<td>Training producer groups, facilitating farmer experimentation, supporting M&amp;E efforts</td>
<td>Conduct breeding to combine multiple traits into widely-adaptable germplasm</td>
</tr>
<tr>
<td>Output 2.3: End-use production technologies</td>
<td>Conduct specific value chain analyses, and provide facilitation for enhanced interactions Conduct breeding of hybrid parents and hybrids with required qualities and productivity</td>
<td>Methodological and analytical support, for both quality analyses, as well as market analyses</td>
<td>Contribute efforts towards facilitating purchase form small-holder farmers, based on value chain analyses</td>
<td>Organize producers groups of small holder farmers for market access and increased profitability of production, facilitate dialogue between industry, research and producers</td>
<td>Support hybrid, and hybrid parent breeding for quality and productivity, facilitate industry – researcher – development dialogue; monitor progress and document advances, especially benefits to small-holder producers</td>
</tr>
<tr>
<td>Output 2.4: Post-harvest &amp; processing technologies</td>
<td>Develop capacity for processing business incubation; conduct grain quality evaluations</td>
<td>Food processing research, Engineering research</td>
<td>Research into marketable processed food products from dryland cereals; contribute efforts towards facilitating purchase form small-holder farmers, based on value chain analyses</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Output</td>
<td>NARES in Africa &amp; Asia</td>
<td>ARIs</td>
<td>Private Sector</td>
<td>NGOs, CSOs, Farmers Organizations</td>
<td>CGIAR Centers</td>
</tr>
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<tr>
<td><strong>Output 2.5: Market access technologies</strong></td>
<td>Develop production technology packages for specific production and market opportunities; support training, and organizing producer groups</td>
<td>Methodological support for institutional analyses and developments</td>
<td>Develop options for providing production credit to smallholder dryland cereal farmers</td>
<td>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</td>
<td>Contribute to the identification of best bet production packages, assess opportunities for using new communication tools</td>
</tr>
</tbody>
</table>

**Strategic Objective 3 - Optimizing nutritional value of dryland cereals**

| Output 3.1: Knowledge & data on nutritional targets | Conduct data collection for priorities, participate in priority setting, identify policy changes required | Conduct data collection for priorities, participate in priority setting, identify policy changes required; nutrition research capacity, and linkage to medical research as required | Openness for collaboration on nutritional quality of their products | Support the implementation of nutrition assessments, their interpretation, and dissemination of results, contribute to priority setting, and the identification of targeted policy changes | Facilitate data collection and storage/analysis for priorities, participate in priority setting, identify policy changes required |
| Output 3.2: Nutritionally enhanced varieties | Conduct breeding of local varieties | Support with grain quality analyses and tools for studying bioavailability | Collaborate in variety/hybrid testing and effective seed and information dissemination | Raise producers awareness, conduct training and information campaigns, focusing on women | Conduct breeding to combine multiple traits into widely-adaptable germplasm |
| Output 3.3: Tools & crops management practices | Conduct on-station and on-farm trials on management options | Support grain quality analyses and tools for studying bioavailability, especially with research on food processing options, efficacy studies | Collaborate on processing options, participate in or conduct marketing studies | Raise consumer awareness, participate in product evaluation, contribute to priority setting | Identify management options, conduct on-station and on-farm trials on crop management options, food processing options |
| Output 3.4: Strengthened capacity on nutritional value | Conduct training in crop improvement & management for nutritional-enhancement, post-harvest processing for nutrition | Assist in training in genomics, crop improvement (including marker-assisted) & management, seed systems | Participate and contribute to training programs | Conduct and participate in specific training programs | Facilitate training in genomics, crop improvement (including marker-assisted) & management for nutritional-enhancement; prepare training material on nutrition messages |
Indicative List of Potential Partners

National Agricultural Research and Extension Programs in Africa and Asia

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

Advanced Research Institutes

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

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

NGOs, CSOs, Farmer Organizations
Africa Harvest, Kenya
AGRA
Amedd
ASEDES, Mali
Association des Organisations Professionnelles Paysannes (AOPP), Mali
Coprosem, ULPC
Farm Radio International, Canada
Fuma Gaskya, Niger
Helen Keller Institute
IFAD-CBARDP, Nigeria
IFAD-PDRD, Burkina Faso
IFAD-PPIIDA, Niger
Institut Polytechnique Rural, Mali
Minim Sông Pânga, Burkina Faso
Mooriben, Niger
Purchase for Progress, WFP
Technoserve

Union de Groupement pour la commercialisation des Produits Agricole, Boucle du Mouhoun (UGCPA/BM), Burkina Faso
Union Locale des Producteurs de Cereales (ULPC), Mali

CGIAR Centers
CIMMYT
ICARDA
ICRISAT
IFPRI
ILRI
IRRI
**GENDER STRATEGY**

Women produce over half the food in many developing countries, bear most responsibility for household food security, and contribute to household well being 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 income 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.

Furthermore, evidence shows the traditional role of women as seed selectors and preservers. Women were probably the first to recognize the value of seeds as planting material, and they remain the guardians of seeds. This places women in a key position for participatory varietal selection and seed production. Strategic Objective 1 will mainstream gender-disaggregated analyses of the roles of women and men in the food value-chain. Proactive strategies will be developed that strengthen the capacity of the most marginal farmers and women to participate in technology development.

Women farmers will be targeted for accessing seed of new varieties, and women entrepreneurs also will be encouraged to form alternative farmer-based seed production and marketing schemes. These could be linked to on-farm processing and value addition of food/industrial products, which are primarily operated by women. The effectiveness of these activities will be monitored through an assessment of how effectively farmers are involved in the participatory breeding programs and how relevant the improved crops are at household level.

**Gender and Strategic Objective 2**
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.

**Gender and Strategic Objective 3**
The long-term health effects of malnutrition are most serious for young children and for expecting and nursing mothers. Strategic Objective 3 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-
physically map and sequence the barley gene space, with the near-term need being the

varieties.

regarding food patterns and priorities. Men and women will be sensitized about the existence of

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

improving cereal storage and for preserving or improving nutritional properties while cooking. Men

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
identical 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 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 ARIIs 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 MP, 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 CEREALES will partner with several other CRPs, providing outputs, drawing inputs and engaging in joint activities with them (Table 6). The connection points are evident from the activities and outputs in our three Strategic Objectives. DRYLAND CEREALES 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 byproducts. Feed and fodder improvement will be done in close collaboration with CRP 3.7 and its feed- and fodder-related activities. DRYLAND CEREALES research will have important synergistic relationships with crop CRPs 3.1 (WHEAT), 3.2 (MAIZE), 3.3 (GRISP) and 3.5 (Grain Legumes Value Alliance). 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, CRPs 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 CEREALES 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 CEREALES, working jointly with CRPs 1.1, 2 and 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 CEREALES 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 6. Envisioned linkages and collaboration between DRYLAND CEREALS and other CRPs

<table>
<thead>
<tr>
<th>CGIAR Research Program</th>
<th>Outputs from DRYLAND CEREALS</th>
<th>Inputs to DRYLAND CEREALS</th>
<th>Joint Actions with DRYLAND CEREALS</th>
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</table>
| CRP 1.1 - Integrated Agricultural Production Systems for the 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 |
<table>
<thead>
<tr>
<th>CGIAR Research Program</th>
<th>Outputs from DRYLAND CEREALS</th>
<th>Inputs to DRYLAND CEREALS</th>
<th>Joint Actions with DRYLAND CEREALS</th>
</tr>
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<tbody>
<tr>
<td>CRP3.1 - WHEAT</td>
<td>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.</td>
<td>Genetic/genomic/phenotypic information in wheat, maize and rice on traits common with dryland cereals</td>
<td>(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.</td>
</tr>
<tr>
<td>CRP3.2 – MAIZE</td>
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<tr>
<td>CRP3.3 – GRISP: A Global Rice Science Partnership</td>
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<tr>
<td>CRP 3.5 - Grain Legumes Value Alliance</td>
<td>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</td>
<td>Genetic/genomic/phenotypic information in grain legumes on traits common with dryland cereals</td>
<td>(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.</td>
</tr>
<tr>
<td>CRP 3.7 - Sustainable Staple Food Productivity Increase for Global Food Security: Livestock and Fish</td>
<td>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</td>
<td>Phenotyping of dryland cereal varieties to determine feed/fodder quality and processing options</td>
<td>(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.</td>
</tr>
<tr>
<td>CGIAR Research Program</td>
<td>Outputs from DRYLAND CEREALS</td>
<td>Inputs to DRYLAND CEREALS</td>
<td>Joint Actions with DRYLAND CEREALS</td>
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| 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 |
| 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 Regional/Research Program 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 6) 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.

ROLES AND RESPONSIBILITIES

As with all CRPs, the *Lead Center* (in this case, ICRISAT) will sign a Performance Contract with the CGIAR’s Consortium Board 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.

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 Regional/Research Program Coordinators and provide required support, and
- Ensure that performance contracts are successfully managed, including the management of risks.

Overall governance 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, and whose members 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, and 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 Regional/Research Program Coordinators (see below) and an appropriate research director from key partners who are not represented by a Regional Program 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 Scientific Advisory Pool. All such interactions will be properly recorded and made available to the SC.

The DRYLAND CEREALS Director will be contracted 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 will be implemented across the four regions – West and Central Africa, East and Central Africa, West Asia and North Africa, and South Asia – and will be implemented under the auspices of a **Regional Program Coordinator**, which will be at least a half-time appointment of a scientist/manager and who will continue to be affiliated with their home institution, with the agreement of the institution. Efforts will be made to have inclusive partner representation across the 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.

Each Regional Program Coordinator will chair a Regional Coordinating Committee (RCC) composed of scientists and partners in each the region. The RCC will assist the RPC in effectively implementing, coordinating, monitoring and assessing the research activities and partnerships in the region.

A **Scientific Advisory Pool** 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 to 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**

Intellectual property (IP) management is based on the overall IP policy of the Alliance of CGIAR-supported Centers, which is driven by the mission of the CGIAR and the imperative that the products of the Centers’ research should be international public goods.

The Centers 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 Centers 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).

**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 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**

DRYLAND CEREALS began the proposal development process with delineating the partners’ vision of realistic impacts to be achieved through collaborative R4D by 2020. We then outlined an initial 6-year program framework. We then focused on the first three years to develop milestones (through 2014). 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.

As we developed this document, for ease of reference we decided to keep our 2012-2014 projected milestones close to the strategic objectives to which they relate and the R4D activities that are meant to achieve them.

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 livelihood security, and reducing environmental degradation (Table 7).

To effectively ensure that DRYLAND CEREALS achieves these outcomes, *ex ante* impact assessments will be conducted during the project development stage. Building from that base, monitoring and evaluation (M&E) studies will be conducted during DRYLAND CEREALS implementation. 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>
<thead>
<tr>
<th>M&amp;E Indicators</th>
<th>Type of output</th>
<th>Measurement</th>
<th>Method of M&amp;E</th>
<th>Implementing Agency</th>
<th>Frequency</th>
<th>M&amp;E Agency</th>
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<tr>
<td>Enhanced genetic resources and new sources of resistance to abiotic and biotic stresses and improved nutritional quality, productivity and product quality</td>
<td>Quality germplasm/seed material Quantity of output</td>
<td>a) No. of accessions screened and characterized. b) Crop productivity and nutritional composition c) Consumer acceptance of product quality</td>
<td>Field and laboratory inspection and analysis of data generated</td>
<td>IARC, NARES, NGOs, Pvt Sector</td>
<td>Seasonal/Annually</td>
<td>Implementing/Executing/Independent agency</td>
</tr>
<tr>
<td>Leading edge scientific knowledge on genetics and genomics published</td>
<td>Publications</td>
<td>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.</td>
<td>Analysis of data on performance of crop variety at different locations. Peer review. Classification of publications by type, author, collaborator. Citation index.</td>
<td>IARC, NARES</td>
<td>Annually</td>
<td>Implementing/Executing agency</td>
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<tr>
<td>M&amp;E Indicators</td>
<td>Type of output</td>
<td>Measurement</td>
<td>Method of M&amp;E</td>
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<td>Cultivars derived from IARC germplasm released by NARES and grown on a large scale along with recommended crop management practices</td>
<td>Cultivar (seed material)/ Crop management Technology</td>
<td>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</td>
<td>Field inspection. Visits to varietal trails, field days and demonstration plots. Analysis of field data generated. Focused group discussion</td>
<td>IARC, NARES</td>
<td>Monthly/ Quarterly</td>
<td>Implementing/ Executing agency</td>
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<td>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</td>
<td>Availability of quality seed: Breeder/Foundation/ Certified seed,</td>
<td>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.</td>
<td>Field visits and inspection. Certification/Quality accreditation. Seed market surveys, number of dealer/agencies involved in seed supply. Reduced seed cost/unit.</td>
<td>Pvt Sector, NGOs, NARES, IARC</td>
<td>Half-yearly</td>
<td>Implementing/ Executing/ Independent agency</td>
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<td><strong>M&amp;E Indicators</strong></td>
<td><strong>Type of output</strong></td>
<td><strong>Measurement</strong></td>
<td><strong>Method of M&amp;E</strong></td>
<td><strong>Implementing Agency</strong></td>
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| 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

Details on the projected DRYLAND CEREALS budget for 2011-2013 are presented in Table 8. The budget presents the required level of income from CGIAR Windows and bilateral funding, and expenses by Strategic Objective and by output, partner and expense category.

The budget was developed by initially allocating existing bilateral project budgets for ICRISAT, ICARDA and the GCP to Strategic Objective outputs. The total required budget for each output was determined based on projected key milestones. Each output budget represents the requirements for ICRISAT, ICARDA, the GCP and partners to be initially funded by DRYLAND CEREALS.

Costs for gender research and analysis are budgeted separately and include scientists’ time and operating expenses across the partners. Approximately 5% (US$ 4.3M) of the total first three-year budget has been specifically allocated for gender-related research. ICRISAT and ICARDA have gender specialists who will devote significant time to DRYLAND CEREALS researching gender aspects of targeting, planning, design and implementation.

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. This includes the costs for the CRP Director (40% for 2011 and 100% for 2012 and 2013), global coordination meetings involving partners to be held at least twice each year, regional coordination meetings twice each year, the steering committee to meet once physically each year and once virtually, and the travel and honoraria costs for advisory pool members. The total CRP management budget is 3% of the total CRP budget for 2011-2013. Efforts will be made to maintain, if not reduce, the costs of CRP management, but it will be critical to allocate funds to management during the first phase to enable the required staffing, communications and meetings.

Partners are critical for the success of DRYLAND CEREALS and a total of 23% of the three-year budget has been allocated for them. The GCP budget (3%) is entirely for partners and an additional 20% has been identified for R4D and development partners. These funds will be used to support specific research under each Strategic Objective output based on agreed work plans. Much of the partner budget is already allocated based on existing bilateral projects, although these will be enhanced with other funding from the CRP.

Several partners, especially IRD, CIRAD, INTSORMIL and ICAR, will also make significant in-kind contributions to DRYLAND CEREALS. 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 the 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.

Funding for DRYLAND CEREALS (approximately US$ 89 million over three years) will be provided by CGIAR Windows 1 and 2, and from bilateral projects already secured. Realizing that full support from the CGIAR Windows is unlikely during the first three years, efforts to secure additional bilateral support will continue, although at a reducing level each year. Over the first three years, funding from CGIAR Windows 1 and 2 is proposed to cover 64% of the total expense budget, with the remaining 34% from bilateral (secured and pending) sources.
Table 8. DRYLAND CEREALS budget (2011-2013)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CGIRAR Window 1 &amp; 2: Research</td>
<td>7,033,000</td>
<td>19,586,000</td>
<td>27,779,000</td>
<td>54,398,000</td>
<td>61%</td>
</tr>
<tr>
<td>CGIRAR Window 1 &amp; 2: CRP Management</td>
<td>394,600</td>
<td>1,071,100</td>
<td>1,096,700</td>
<td>2,562,400</td>
<td>3%</td>
</tr>
<tr>
<td>Bilateral Funding (secured)</td>
<td>10,773,688</td>
<td>6,794,056</td>
<td>4,017,589</td>
<td>21,585,333</td>
<td>24%</td>
</tr>
<tr>
<td>Bilateral Funding (pending)</td>
<td>4,152,000</td>
<td>3,119,000</td>
<td>2,947,000</td>
<td>10,218,000</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Total CGIRAR Window 1 &amp; 2</strong></td>
<td>7,427,600</td>
<td>20,657,100</td>
<td>28,875,700</td>
<td>56,960,400</td>
<td>64%</td>
</tr>
<tr>
<td><strong>Total Bilateral</strong></td>
<td>14,925,688</td>
<td>9,913,056</td>
<td>6,964,589</td>
<td>31,803,333</td>
<td>36%</td>
</tr>
<tr>
<td><strong>Grand Total Income</strong></td>
<td>22,353,288</td>
<td>30,570,156</td>
<td>35,840,289</td>
<td>88,763,733</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Expenses by Strategic Objective**

**SO 1 Increasing & sustaining the production of dryland cereals**

1.1 Targeting & policies | 638,730 | 839,145 | 977,654 | 2,455,529 | 3% |
1.2 Tools & methods | 1,277,460 | 1,678,290 | 1,955,308 | 4,911,058 | 6% |
1.3 Stress tolerant varieties | 2,767,830 | 3,636,295 | 4,236,501 | 10,640,626 | 12% |
1.4 Hybrids | 1,276,460 | 1,678,290 | 1,955,308 | 4,910,508 | 6% |
1.5 Crop management options | 851,640 | 1,118,860 | 1,303,539 | 3,274,039 | 4% |
1.6 Effective seed & input systems | 2,129,100 | 2,797,150 | 3,260,847 | 8,187,097 | 9% |
1.7 Strengthened knowledge & capacity | 1,064,550 | 1,398,575 | 1,629,424 | 4,092,548 | 5% |
**Total Strategic Objective 1** | 10,005,770 | 13,146,604 | 15,318,582 | 38,470,956 | 43% |

**SO 2 Contributing to economic growth**

2.1 Knowledge & data on value addition | 851,640 | 1,118,860 | 1,303,539 | 3,274,039 | 4% |
2.2 Improved dryland cereals for livestock | 2,129,100 | 2,797,150 | 3,258,847 | 8,185,097 | 9% |
2.3 Efficient production technologies | 1,064,550 | 1,398,575 | 1,629,424 | 4,092,548 | 5% |
2.4 Improved post-harvest & processing technologies | 1,277,460 | 1,678,290 | 1,956,308 | 4,912,058 | 6% |
2.5 Improved dryland cereal technologies for markets | 1,064,550 | 1,398,575 | 1,629,424 | 4,091,548 | 5% |
**Total Strategic Objective 2** | 6,386,300 | 8,391,449 | 9,777,541 | 24,555,291 | 28% |

**SO 3 Optimizing nutritional value of dryland cereals**

3.1 Knowledge on malnutrition | 851,640 | 1,118,860 | 1,303,539 | 3,274,039 | 4% |
3.2 Nutritious varieties | 1,916,190 | 2,517,435 | 2,932,962 | 7,366,587 | 8% |
3.3 Tools & crop management practices | 1,063,550 | 1,398,575 | 1,630,424 | 4,092,548 | 5% |
3.4 Strengthened capacity | 1,064,550 | 1,398,575 | 1,629,424 | 4,092,548 | 5% |
**Total Strategic Objective 3** | 4,895,930 | 6,433,445 | 7,496,348 | 18,825,723 | 21% |

**Total Strategic Objectives**

21,287,999 | 27,971,498 | 32,592,472 | 81,851,969 | 92% |

**Gender Research & Analysis**

670,689 | 1,527,558 | 2,151,117 | 4,349,364 | 5% |

**CRP Management**

394,600 | 1,071,100 | 1,096,700 | 2,562,400 | 3% |

**Total Expenses**

22,353,288 | 30,570,156 | 35,840,289 | 88,763,733 | 100% |

**Expenses by Partner**

ICRISAT | 14,008,000 | 17,140,435 | 20,903,784 | 52,052,219 | 59% |
ICARDA | 4,119,000 | 4,656,000 | 5,272,000 | 14,047,000 | 16% |
GCP | 1,020,688 | 934,056 | 831,589 | 2,786,333 | 3% |
Partners | 8,811,000 | 6,768,565 | 7,736,216 | 23,315,782 | 26% |
CRP Management | 394,600 | 1,071,100 | 1,096,700 | 2,562,400 | 3% |

**Total Expenses**

22,353,288 | 30,570,156 | 35,840,289 | 88,763,733 | 100% |

**Expenses by Category**

**Research**

Personnel Costs | 8,069,760 | 9,698,712 | 11,612,284 | 29,380,756 | 33% |
Supplies and Services | 3,271,600 | 3,865,120 | 4,560,840 | 11,697,560 | 13% |
Travel | 1,294,800 | 1,546,560 | 1,843,420 | 4,684,780 | 5% |
Workshops/Conferences/Training | 714,600 | 836,520 | 978,140 | 2,529,260 | 3% |
Capital Expenditures | 580,400 | 697,780 | 836,210 | 2,114,390 | 2% |
Partners | 3,831,688 | 7,820,956 | 8,895,639 | 20,548,283 | 23% |
Institutional Management | 4,195,840 | 5,033,408 | 6,017,056 | 15,246,304 | 17% |
CRP Management | 394,600 | 1,071,100 | 1,096,700 | 2,562,400 | 3% |

**Total Expenses**

22,353,288 | 30,570,156 | 35,840,289 | 88,763,733 | 100% |
<table>
<thead>
<tr>
<th>CRP Management Expenses</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global Leadership</td>
<td>173,800</td>
<td>274,000</td>
<td>278,000</td>
<td>725,800</td>
<td>28%</td>
</tr>
<tr>
<td>CRP Global Coordination Meetings</td>
<td>19,500</td>
<td>72,600</td>
<td>76,400</td>
<td>168,500</td>
<td>7%</td>
</tr>
<tr>
<td>Regional Coordination &amp; Meetings</td>
<td>152,500</td>
<td>622,000</td>
<td>635,500</td>
<td>1,410,000</td>
<td>55%</td>
</tr>
<tr>
<td>Steering Committee</td>
<td>32,500</td>
<td>68,300</td>
<td>71,000</td>
<td>171,800</td>
<td>7%</td>
</tr>
<tr>
<td>Advisory Pool</td>
<td>16,300</td>
<td>34,200</td>
<td>35,800</td>
<td>86,300</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Total CRP Management Expenses</strong></td>
<td><strong>394,600</strong></td>
<td><strong>1,071,100</strong></td>
<td><strong>1,096,700</strong></td>
<td><strong>2,562,400</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

### REFERENCES


APPENDICES

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, 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 km²).

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 A1-1 and Figures A1-1 & A1-2). 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.

<table>
<thead>
<tr>
<th>Region</th>
<th>Production Growth Rate (%)</th>
<th>Area Growth Rate (%)</th>
<th>Yield Growth Rate (%)</th>
<th>Regional Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>0.21</td>
<td>-0.36</td>
<td>-0.78</td>
<td>-1.28</td>
</tr>
<tr>
<td>Africa</td>
<td>1.12</td>
<td>1.27</td>
<td>0.08</td>
<td>0.55</td>
</tr>
<tr>
<td>East Africa</td>
<td>-1.00</td>
<td>3.33</td>
<td>-0.30</td>
<td>0.91</td>
</tr>
<tr>
<td>North Africa</td>
<td>1.53</td>
<td>0.58</td>
<td>0.00</td>
<td>0.58</td>
</tr>
<tr>
<td>North America</td>
<td>-1.20</td>
<td>-3.32</td>
<td>-2.27</td>
<td>-3.46</td>
</tr>
<tr>
<td>South America</td>
<td>5.30</td>
<td>5.08</td>
<td>1.89</td>
<td>1.75</td>
</tr>
<tr>
<td>Asia</td>
<td>4.44</td>
<td>-0.90</td>
<td>4.46</td>
<td>-2.71</td>
</tr>
<tr>
<td>Central Asia</td>
<td>NA ²</td>
<td>-2.33</td>
<td>NA ²</td>
<td>-5.66</td>
</tr>
<tr>
<td>East Asia</td>
<td>0.74</td>
<td>-2.41</td>
<td>0.51</td>
<td>-5.93</td>
</tr>
<tr>
<td>South Asia</td>
<td>1.40</td>
<td>-0.11</td>
<td>-1.60</td>
<td>-1.12</td>
</tr>
<tr>
<td>West Asia</td>
<td>3.43</td>
<td>-0.27</td>
<td>3.52</td>
<td>-1.38</td>
</tr>
<tr>
<td>Europe</td>
<td>-0.54</td>
<td>-0.03</td>
<td>-2.39</td>
<td>-1.26</td>
</tr>
<tr>
<td>Oceania</td>
<td>0.92</td>
<td>1.28</td>
<td>0.08</td>
<td>2.80</td>
</tr>
</tbody>
</table>

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

Figure 1-1. Global annual barley area harvested, production and productivity statistics (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.

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, F₁ and BCnF₁ crosses) to facilitate recurrent selection to develop broad-based and more durable, host-plant resistance to blast, and to produce backcross F₁ 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 \textit{(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 (see Table A1-2 and Figures A1-3 & A1-4). 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 14.1 million 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.

<table>
<thead>
<tr>
<th>Region/ Country</th>
<th>Production Growth Rate (%)</th>
<th>Area Growth Rate (%)</th>
<th>Yield Growth Rate (%)</th>
<th>Regional Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>0.14</td>
<td>1.59</td>
<td>0.09</td>
<td>-0.23</td>
</tr>
<tr>
<td>Africa</td>
<td>3.61</td>
<td>3.17</td>
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</tr>
<tr>
<td>ESA</td>
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<td>0.01</td>
</tr>
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<td>WCA</td>
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<td>5.19</td>
<td>1.03</td>
</tr>
<tr>
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<td>2.58</td>
<td>4.87</td>
</tr>
<tr>
<td>Asia</td>
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<td>-2.50</td>
<td>-1.21</td>
</tr>
<tr>
<td>Eastern Asia</td>
<td>-5.52</td>
<td>-5.44</td>
<td>-7.00</td>
<td>-5.50</td>
</tr>
<tr>
<td>Southern Asia</td>
<td>0.32</td>
<td>1.24</td>
<td>-1.99</td>
<td>-0.83</td>
</tr>
<tr>
<td>India</td>
<td>1.50</td>
<td>2.82</td>
<td>-1.06</td>
<td>2.87</td>
</tr>
</tbody>
</table>

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).

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\(^{-1}\) 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.
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 (see Table A1-3 and Figures A1-5 & A1-6). 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.

<table>
<thead>
<tr>
<th>Region/Country</th>
<th>Production Growth Rate (%)</th>
<th>Area Growth Rate (%)</th>
<th>Yield Growth Rate (%)</th>
<th>Regional Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>-1.40</td>
<td>-0.40</td>
<td>-0.67</td>
<td>-0.08</td>
</tr>
<tr>
<td>Africa</td>
<td>2.37</td>
<td>2.68</td>
<td>3.42</td>
<td>1.53</td>
</tr>
<tr>
<td>ESA</td>
<td>-1.62</td>
<td>1.65</td>
<td>-0.80</td>
<td>1.08</td>
</tr>
<tr>
<td>WCA</td>
<td>4.02</td>
<td>3.00</td>
<td>5.28</td>
<td>1.72</td>
</tr>
<tr>
<td>North America</td>
<td>-2.46</td>
<td>-4.74</td>
<td>-3.43</td>
<td>-3.87</td>
</tr>
<tr>
<td>Latin America and the Caribbean</td>
<td>-8.81</td>
<td>1.76</td>
<td>-4.56</td>
<td>6.78</td>
</tr>
<tr>
<td>Asia</td>
<td>-1.16</td>
<td>-3.39</td>
<td>-2.87</td>
<td>-2.66</td>
</tr>
<tr>
<td>Eastern Asia</td>
<td>-2.73</td>
<td>-6.17</td>
<td>-5.99</td>
<td>-7.32</td>
</tr>
<tr>
<td>Southern Asia</td>
<td>-0.40</td>
<td>-2.44</td>
<td>-2.49</td>
<td>-2.83</td>
</tr>
<tr>
<td>India (post-rainy season)²</td>
<td>0.52</td>
<td>-0.40</td>
<td>-1.33</td>
<td>-1.54</td>
</tr>
<tr>
<td>India (rainy season)³</td>
<td>0.52</td>
<td>-3.27</td>
<td>-1.33</td>
<td>-3.31</td>
</tr>
</tbody>
</table>

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).

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.
APPENDIX 2: PROFILES OF INITIAL R4D PARTNERS

Most DRYLAND CEREALS partners have interdisciplinary teams of scientists with well-developed methodologies for screening against the key dryland cereal abiotic and biotic stresses and have established strong collaborative relationships with NARS partners where adaptation and selection activities are conducted. ILRI is similarly well equipped to address livestock feed, fodder and market issues and has an international network of partners in place that can be used as the basis for meeting the needs of smallholders operating mixed crop/livestock enterprises. The Generation Challenge Program (GCP) is also an Initial Principal 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.

The International Center for Research in the Semi-Arid Tropics (ICRISAT) 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. (www.icrisat.org)

The International Center for Agricultural Research in the Dry Areas (ICARDA) 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. (www.icarda.org)
The **Generation Challenge Programme (GCP)** 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 trait evaluation, informatics tools, support services, capacity development and community support for conducting genomics research and integrated breeding projects. ([www.generationcp.org](http://www.generationcp.org))

The **Indian Council of Agricultural Research (ICAR)** 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.

([www.icar.org](http://www.icar.org))

The **L’institut de recherche pour le développement (IRD)** 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 are 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, 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. (www.ird.fr)

The Centre de coopération internationale en recherché agronomique pour le développement (CIRAD) 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 90 countries. 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. (www.cirad.fr/en)
The International Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL) 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, folio 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. (www.intsormil.org)
### APPENDIX 3: DRYLAND CEREAL CURRENT BILATERAL-FUNDED R4D PROJECTS

<table>
<thead>
<tr>
<th>Title</th>
<th>Donor/Funding</th>
<th>Countries</th>
<th>Crops</th>
<th>Partners</th>
<th>Summary</th>
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<tbody>
<tr>
<td>Harnessing Opportunities for Productivity Enhancement (HOPE) of Sorghum and Millets in Sub-Saharan Africa and South Asia</td>
<td>Bill &amp; Melinda Gates Foundation</td>
<td>Burkina Faso, Eritrea, Ethiopia, India, Kenya, Mali, Niger, Nigeria, Sudan, Tanzania, Uganda</td>
<td>Finger millet, Pearl millet, Sorghum</td>
<td>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, Maize Harvest, Kenya</td>
<td>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.</td>
</tr>
<tr>
<td>PROMISO: Strengthening West African farmers’ and Researchers’ Capacity to Jointly Adapt New Pearl Millet and Sorghum Varieties and Crop Production Innovations</td>
<td>EC</td>
<td>Benin, Burkina Faso, Ghana, Mali, Niger, Senegal</td>
<td>Pearl millet, Sorghum</td>
<td>ICRISAT, NARS in target countries</td>
<td>The overall objective of the PROMISO project is to strengthen the capacity to produce higher and more stable grain yields of sorghum and pearl millet among poor rural households in West Africa. The project plans to contribute 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) Increase farmer’s varietal options for sorghum and pearl millet; (3) Develop training resources in a range of media forms for continued and large scale farmer, researcher, and development community capacity building; (4) enhance researchers’ and development partners’ capacities to monitor outcomes and impacts; (5) Strengthen Regional coordination and monitoring capacity with ECOWAS – CORAF; and (6) Enhance visibility of EU and CORAF and awareness of the vital role of sorghum and pearl millet production systems for food security, nutrition, and income.</td>
</tr>
<tr>
<td>Title</td>
<td>Donor/Funding</td>
<td>Countries</td>
<td>Crops</td>
<td>Partners</td>
<td>Summary</td>
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<tr>
<td>Establishing a Molecular Breeding Program Based on the Aluminum Tolerance Gene, Altₘᵦ, and the P Efficiency QTL, Pup-1, for Increasing Sorghum Production in Sub-Saharan Africa</td>
<td>Generation Challenge Program 50.54SM (2010-2013)</td>
<td>Brazil, Kenya, Mali, Niger</td>
<td>Sorghum</td>
<td>ICRISAT, EMBRAPA, Brazil, Institut National de Recherches Agronomiques du Niger (INRAN), Niger, Moi University, Kenya, Cornell, USA, USDA/ARS, USA</td>
<td>In Africa, a combination of soil constraints and a lack of adapted crop cultivars are clearly two of the most important factors responsible for low grain yield. Low productivity is a serious problem in many parts of Africa where sorghum is a staple food supporting millions of the rural poor. Within the Sorghum Pup1 project in this Comparative Genomics Challenge Initiative we will attempt to validate homologs of the major rice P uptake QTL, Pup1, functioning as P deficiency tolerance genes in sorghum, and investigate a similar role for the major Al tolerance gene, Altₘᵦ. If successful, we will develop molecular markers for Pup1 validated homologs for marker assisted selection for P deficiency tolerance in sorghum. We are also developing and validating gene-specific markers for Altₘᵦ within other competitive GCP projects. The project described here implements 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 phosphorous 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. This project will build upon the progress achieved in the GCP commissioned project, “Assessment of the breeding value of superior haplotypes for Altₘᵦ, a major Al tolerance gene in sorghum: linking upstream genomics to acid soil breeding in Niger and Mali (ALTFIELD). The results will be validated in Kenya, Mali and Niger as well as in Embrapa Maize and Sorghum (Embrapa MS) using S1 and S2 selected progenies from RMPs in phenotyping sites specifically developed for this purpose. 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.</td>
</tr>
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<td>Title</td>
<td>Donor/Funding</td>
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<td>Crops</td>
<td>Partners</td>
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| Enhancing Sorghum Grain Yield and Quality for the Sudano-Sahelian Zone of West Africa using the Backcross Nested Association Mapping (BCNAM) Approach | Generation Challenge Program  
$0.800M  
(2010-2013)                                                             | Mali       | Sorghum | Institut d’Economie Rurale (IER), Mali  
CIRAD, France  
ICRISAT                                                        | Sorghum improvement in Africa deals with a wide range of harsh and highly variable environments. The local varieties are specifically adapted to the biotic and abiotic constraints and have an excellent grain quality but with low yield potentials. Sorghum breeding programs in West Africa must work with a considerable number of traits, and address the specific adaptation requirements for specific and variable agro-ecologies. This project will enhance the capacity of national and international breeding programs while using sorghum germplasm diversity and advanced molecular tools. This 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 back-crosses carried out with 3 recurrent parents which represent the target ideotypes to be improved. The donor parents include 10 common donors and 20 specific donors representing the diversity of the improved and local varieties. 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. |
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<tr>
<td>Improving Phosphorus Efficiency in Sorghum by the Identification and Validation of Sorghum Homologs for Pup1, a Major QTL Underlying Phosphorus Uptake in Rice</td>
<td>Generation Challenge Program $0.805M (2010-2013)</td>
<td>Mali, Niger</td>
<td>Sorghum</td>
<td>Cornell, USA, Institut National de Recherches Agronomiques du Niger (INRAN), Niger, Moi University, Kenya, ICRISAT, EMBRAPA, Brazil, JIRCAS, Japan, USDA/ARS, USA</td>
<td>Low productivity due to soil constraints and a lack of properly adapted crop cultivars is a serious problem in many parts of Africa, where sorghum is a staple food supporting millions of the rural poor. Pup1 is a major QTL located on rice chromosome 12 that underlies phosphorus efficiency and has the potential to increase P acquisition efficiency in other cereals. Research findings from a long term collaboration between IRRI and JIRCAS has resulted in the fine mapping of the Pup1 locus to a ~150 Kb region on chr 12, and 2-4 high quality Pup1 candidate genes have been identified. Taking advantage of the complete sequence of the sorghum genome, we will establish a framework based on comparative genomics to identify sorghum Pup1 homologs and will validate their role as bona fide genes underlying tolerance to P deficiency. This research will be based primarily on association analysis to identify statistically significant associations between allelic variation for Pup1 candidate genes and P efficiency assessed both in the field and under controlled conditions in the laboratory and greenhouse. Positive associations will be validated by bi-parental mapping and analysis of near-isogenic lines. The Al tolerance gene, Alt$<em>{al}$, is an Al-induced root citrate efflux transporter and citrate can mobilize P that is fixed in the soil clay fraction and increase its availability for root P uptake. Therefore, we will use the same approach to study a possible synergistic role of Alt$</em>{al}$ 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 (see sorghum marker assisted breeding project based on Alt$_{al}$/Pup1 in this Challenge Initiative - SorghumMB) should functional Pup1 homologs not be found in sorghum. Thus, this project sets the foundation for a molecular breeding program targeting marginal soil areas in southern Mali, Niger and Kenya and other areas of Sub-Saharan Africa to improve food security and farmer’s income.</td>
</tr>
<tr>
<td>Title</td>
<td>Donor/Funding</td>
<td>Countries</td>
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<tr>
<td>Improve sorghum productivity in semi-arid environments of Mali through integrated MARS</td>
<td>Generation Challenge Program $0.68M (2008-2012)</td>
<td>Mali</td>
<td>Sorghum</td>
<td>IER, Mali Syngenta CIRAD</td>
<td>Sorghum is, together with pearl millet, one the most important cereals in West Africa. It is the second most important crop in Africa after maize. However its yield is low and has not really progressed during the past 20 years. The sorghum production in West Africa is principally based on traditional, low harvest index cultivars and the breeding efforts of the past 40 years showed limited impact. The present project propose to associate 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 multilocal evaluation of the progenies as F4 families, together with genotyping will provide accurate QTL detection for as many traits that have to be considered for breeding. This QTL information will be used in several consecutive cycles of recurrent selection aiming at monitoring recombinations and pyramiding favorable alleles for selected QTLs. All along the recurrent process material will be released for evaluation and selfing to develop new varieties. This project will illustrate through a private-public partnership the value of the MARS approach for sorghum breeding in Mali.</td>
</tr>
<tr>
<td>Title</td>
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<tr>
<td>Improving Post-rainy Sorghum Varieties to Meet the Growing Grain and Fodder Demand in India</td>
<td>ACIAR $1.13M (2008-2012)</td>
<td>India</td>
<td>Sorghum</td>
<td>ICRISAT Directorate of Sorghum Research, India, Queensland Department of Primary Industries &amp; Fisheries, Australia, University of Queensland, Australia ILRI</td>
<td>Postrainy season (Rabi) 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. The grain price equals or exceeds that of wheat and the stover is increasingly demanded by dairy farms, with current prices reaching 30–50% of the grain price for the best quality stover. Improving productivity, while maintaining quality, will offer a very attractive opportunity for Rabi sorghum farmers to improve their incomes. The large emerging fodder/grain markets around cities of Maharashtra, Andhra Pradesh and Karnataka are ready to take up the products of such improvement efforts. For Rabi sorghum, 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). However, a precise use of stay-green QTLs to enhance the agronomic and economic benefits will only be possible once key stay-green QTLs are identified. Therefore, 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. Collaborators are the Indian National Research Centre for Sorghum, the University of Queensland, and the Queensland Department of Primary Industries &amp; Fisheries.</td>
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<tr>
<td>Tackling Abiotic Production Constraints in Pearl Millet and Sorghum-based Agricultural Systems of the West African Sahel</td>
<td>BMZ/GIZ $1.63M (2010-2013)</td>
<td>Burkina Faso Mali Niger Senegal</td>
<td>Pearl millet Sorghum</td>
<td>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</td>
<td>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.</td>
</tr>
<tr>
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<td>Assessing and Refining the Concept of Dynamic Genepool Management and Simultaneous Farmer Participatory Population Improvement in Pearl Millet &amp; Sorghum</td>
<td>McKnight Foundation $0.43M (2010-2014)</td>
<td>Burkina Faso Mali Niger</td>
<td>Pearl millet Sorghum</td>
<td>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</td>
<td>In the previous CCRP-funded project entitled “Farmer-participatory improvement of sorghum and pearl millet genetic resources for increased adaptation to diverse production environments in West Africa”, the “Dynamic Genepool” sub-project combined the concept of dynamic genepool management with farmer-participatory recurrent population improvement and variety development in pearl millet (Niger and Mali) and sorghum (Burkina Faso and Mali). After the creation of site-specific diversified populations and at least three cycles of recurrent population improvement, we now propose to validate and finalize the new sorghum and pearl millet experimental cultivars developed in the first phase, and to 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, where the demand for pearl millet is very high. Furthermore, we seek to enhance progress of pearl millet breeding for resistance to the parasitic weed <em>Striga hermonthica</em> (Del.) Benth. through development of a marker-assisted recurrent selection (MARS) scheme, which will be integrated with the participatory research. This activity will build on and develop further the <em>striga</em>-resistant pearl millet genepool developed in the first phase of the project. 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 <em>in-situ</em> conservation of genetic resources, for both sorghum and pearl millet.</td>
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<tr>
<td>Title</td>
<td>Donor/Funding</td>
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<tr>
<td>Sustaining Farmer-Managed Seed Initiatives for Sorghum and Pearl Millet in Mali, Niger, and Burkina Faso</td>
<td>McKnight Foundation</td>
<td>Burkina Faso Mali Niger</td>
<td>Pearl millet Sorghum</td>
<td>ICRISAT Minim Sông Pânga, Burkina Faso Union de Groupement pour la commercialisation des Produits Agricoles, Boucle du Mouchoun (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 Recherches Agricoles (INERA), Burkina Faso Institut National de la Recherche Agronomique du Niger (INRAN), Niger</td>
<td>Participatory sorghum and pearl millet breeding activities in Mali, Burkina Faso and Niger are identifying new, diverse varieties. These varieties are presently being adopted by farmers in the project areas and beyond. Seed dissemination has been primarily promoted by strengthening seed production and marketing capacities of farmer organizations over the past four years. An initial assessment of seed diffusion in Mali has confirmed that adoption of sorghum varieties is not primarily through formal seed systems supported by commercialization efforts but rather through farmer managed trials, with diffusion to other households in the same or even more distant villages occurring through social networks. Seed commercialization tends to serve farmers in areas outside the immediate project zone. These initial studies have also shown that women are mostly excluded from this type of informal seed exchange. 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.</td>
</tr>
<tr>
<td>Diversification of Pearl Millet Hybrid Parents for Increased Stable Production</td>
<td>Pearl Millet Hybrid Parents Research Consortium (India)</td>
<td>India</td>
<td>Pearl millet</td>
<td>ICRISAT</td>
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<tr>
<td></td>
<td>$0.41M (2009-2013)</td>
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<td>Diversification of Sorghum Hybrid Parents for Increased Stable Production</td>
<td>Sorghum Hybrid Parents Research Consortium (India)</td>
<td>India</td>
<td>Sorghum</td>
<td>ICRISAT</td>
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<tr>
<td>Integrating Genomics and Mapping Approaches to Improve Pearl Millet</td>
<td>BBSRC (UK) $0.23M (2008-2012)</td>
<td>India</td>
<td>Pearl millet</td>
<td>ICRISAT</td>
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<td>Productivity in Drought Prone Regions of Africa and Asia</td>
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<tr>
<td>Transfer of Sorghum and Millet Production, Processing and Marketing</td>
<td>USAID Mission/Mali $5.25M (2007-2012)</td>
<td>Mali</td>
<td>Pearl millet</td>
<td>IER AMEDD CONFIGES CRRA DRA IICEM SAAG 2000</td>
<td>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, Food Processing and Décru Sorghum.</td>
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<tr>
<td>Technologies Program in Mali (INTSORMIL)</td>
<td></td>
<td></td>
<td>Sorghum</td>
<td>INTA CENTA ICTA CHIBAS BIOENERGY DICTA INTA IDIAP</td>
<td>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 CA and Haiti via a rapid (3 year) technology transfer process.</td>
</tr>
<tr>
<td>INTSORMIL</td>
<td>USAID FTF/W Costa Rica El Salvador Guatemala Haiti Honduras Nicaragua Panama Sorghum</td>
<td></td>
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<tr>
<td>International Sorghum and Millet Collaborative Research Support Program (INTSORMIL)</td>
<td>USAID/Washington $12.90M (2006-2011)</td>
<td>Burkina Faso El Salvador Ethiopia Ghana Kenya Mali Nicaragua Nigeria Senegal South Africa Botswana Tanzania Uganda Zambia Mozambique</td>
<td>Finger Millet Pearl Millet Sorghum</td>
<td>Kansas State Univ. Ohio State Univ. Purdue Univ. Texas A&amp;M Univ. West Texas A&amp;M Univ. USDA/ARS DuPont/USA CENTA/El Salvador CNIA/INTA/Nicaragua AMPROSOR/Nicaragua UNA/Nicaragua CNIAB/Nicaragua IESA/Senegal ISRA/Senegal ITA/Senegal CERRA/Niger IER/Mali INRAB/Burkina Faso CREAM/Burkina Faso INERA/Burkina Faso IRSAT/Burkina Faso INRAN/Niger CERRA/Niger Lake Chad Research Station/Nigeria Univ. Maiturgui/Nigeria SARI/Ghana NARO/Uganda ELAR/Ethiopia Alemaya Univ./Ethiopia Axum Univ./Ethiopia KARI/Kenya Tanzania/Hombolo Res. Station Dept. Crop Res./Tanzania Sokone 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</td>
<td>Sorghum and pearl millet are poised to be the major grains of the 21st Century in the semiarid tropics. Significant research advances have been made with resultant technologies starting to be exploited in pilot programs in several regions. Domestic markets for food and feed are increasing rapidly. Success in research and development shows that sorghum and pearl millet are moving from subsistence to cash crops. 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. Although historically recognized as staple crops of the poor. Advantages to growing sorghum and pearl millet are numerous. These crops have enormous genetic variability. Research has resulted in cultivars and hybrids that fit into most production systems. Sorghum and pearl millet can be grown in monoculture, rotated with many other crops, or intercropped with legumes or maize. Plant biomass is used as stover for animals, as building material, or as mulch to improve soil quality and reduce erosion. Dependability of harvests and potential gains of sizable yield increases make sorghum and pearl millet important for the future prosperity of Africa and other regions of the world. Production of sorghum is increasing worldwide, mainly because of rising demand and changes in markets. Sorghum and pearl millet use less water than maize, so in lower rainfall areas, sorghum and pearl millet should be favored over maize. 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.</td>
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<td>Title</td>
<td>Donor/Funding</td>
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<td>Partners</td>
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<tr>
<td>Rapid generation advancement of Korean barley lines through the Double Haploid Technology</td>
<td>Rural Development Administration (S Korea)</td>
<td>S Korea</td>
<td>Barley</td>
<td>ICARDA Rural Development Administration</td>
<td>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.</td>
</tr>
<tr>
<td>Fair Access and Benefit Sharing of Genetic Resources: National Policy Development</td>
<td>IDRC</td>
<td>Jordan</td>
<td>Barley</td>
<td>ICARDA NCARE (Jordan) IDRC (head office)</td>
<td>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: 1. To raise awareness among and empower farmers regarding their voice and rights in policies and laws related to genetic resources; 2. To get participatory plant breeding products recognized legally and properly valued economically; 3. To change policies and laws concerning variety release and seed production in support of participatory plant breeding practices and its products.</td>
</tr>
<tr>
<td>Identification and utilization of durable resistance to diseases in barley in Latin America.</td>
<td>FONTAGRO</td>
<td>Uruguay</td>
<td>Barley</td>
<td>ICARDA Uruguay Peru</td>
<td>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.</td>
</tr>
<tr>
<td>Collaboration in the development of barley germplasm and screening for disease resistance and end-use quality.</td>
<td>Alberta Agricultural and Rural Development (AARD)</td>
<td>Canada</td>
<td>Barley</td>
<td>ICARDA AARD (Canada)</td>
<td>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.</td>
</tr>
<tr>
<td>Integrated improvement of cereal-based cropping systems in rainfed and irrigated areas of Great Jamahirya</td>
<td>ARC – Libya</td>
<td>Libya</td>
<td>Barley</td>
<td>ICARDA ARC-Libya</td>
<td>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.</td>
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<td>Countries</td>
<td>Crops</td>
<td>Partners</td>
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<tr>
<td>Development of Improved Varieties of Malting Barley.</td>
<td>Impulsora Agricola, S.A. de C.V. (IASA)</td>
<td>Mexico</td>
<td>Barley</td>
<td>ICARDA IASA</td>
<td>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.</td>
</tr>
<tr>
<td>Barley Improvement for High Yielding Quality Malt, Food and Feed for Various Agro-ecologies.</td>
<td>ICAR</td>
<td>India</td>
<td>Barley</td>
<td>DWR ICARDA</td>
<td>Develop high yielding barley varieties with superior malting quality for plains of northern India. Develop high yielding barley cultivars for rainfed condition with drought and salinity tolerance in plains and drought &amp; cold tolerance in hills.</td>
</tr>
<tr>
<td>Strategies for Organic and Low-input Integrated Breeding and Management (SOLIBAM)</td>
<td>EU</td>
<td>Ethiopia</td>
<td>Barley</td>
<td>ICARDA EU Partners University of Mekelle, Ethiopia CNOP, Mali</td>
<td>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)</td>
</tr>
<tr>
<td>Improving the Food Security and Climate Change Adaptability of Livestock Producers using the Rainfed Barley-based System in Iraq and Jordan</td>
<td>IFAD</td>
<td>Jordan</td>
<td>Barley</td>
<td>ICARDA NCARE MoA-Iraq</td>
<td>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.</td>
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</tbody>
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### APPENDIX 4: POPULATION, STUNTED CHILDREN, DROUGHT PROBABILITY, NUMBER OF POOR, AND AREA IN FARMING SYSTEMS WITH MORE THAN 800,000 HECTARES OF DRYLAND CEREALS (BARLEY, MILLETS, AND SORGHUM). Data are based on farming systems described by Dixon et al. (2001), poverty data from Wood et al. (2010), and crop distribution maps from You et al. (2000).

#### Farming system
<table>
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<tr>
<th>Farming type</th>
<th>Proportion area planted to dryland cereals (%)</th>
</tr>
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<tbody>
<tr>
<td>Cereal-root crop mixed</td>
<td>38</td>
</tr>
<tr>
<td>Dualistic</td>
<td>38</td>
</tr>
<tr>
<td>Rice-wheat</td>
<td>54</td>
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<tr>
<td>Highland temperate mixed</td>
<td>11</td>
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<tr>
<td>Root crop</td>
<td>37</td>
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<tr>
<td>Pastoral</td>
<td>8</td>
</tr>
<tr>
<td>Subtotal</td>
<td>35</td>
</tr>
<tr>
<td>Asia</td>
<td>18</td>
</tr>
<tr>
<td>Dryland mixed</td>
<td>18</td>
</tr>
<tr>
<td>Highland mixed</td>
<td>39</td>
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<tr>
<td>Rice-wheat</td>
<td>5</td>
</tr>
<tr>
<td>Temperate mixed</td>
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<tr>
<td>Subtotal</td>
<td>12</td>
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<tr>
<td>West Asia, North Africa, Central Asia</td>
<td>36</td>
</tr>
<tr>
<td>Dryland mixed</td>
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<tr>
<td>Highland mixed</td>
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<tr>
<td>Rice-wheat</td>
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<td>Temperate mixed</td>
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<tr>
<td>Subtotal</td>
<td>26</td>
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<tr>
<td>Subtotal for sub-Saharan Africa, Asia &amp; OWANA</td>
<td>20</td>
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<tr>
<td>Latin America</td>
<td>89</td>
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<tr>
<td>Maize-beans (Mesoamerica)</td>
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<tr>
<td>Dualistic</td>
<td>23</td>
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<tr>
<td>Rice</td>
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<td>Lowland rice</td>
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<td>Subtotal</td>
<td>16</td>
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<tr>
<td>Wetland</td>
<td>15</td>
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<tr>
<td>Irrigated</td>
<td>61</td>
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<tr>
<td>Subtotal</td>
<td>31</td>
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<tr>
<td>Grand Total</td>
<td>120</td>
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</table>

#### Sub-Saharan Africa

<table>
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<tr>
<th>Farm type</th>
<th>Total pop. (million)</th>
<th>Rural pop. (million)</th>
<th>Urban pop. (million)</th>
<th>Stunted children (million)</th>
<th>Prevalence stunting (%)</th>
<th>Drought probability (%)</th>
<th>(in farming system area (million))</th>
<th>(in farming system area (million))</th>
<th>(million)</th>
<th>(million)</th>
<th>(million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSA</td>
<td>Smallholder</td>
<td>84.15</td>
<td>69.20</td>
<td>14.95</td>
<td>6.32</td>
<td>39</td>
<td>17</td>
<td>53</td>
<td>74</td>
<td>0.03</td>
<td>6.28</td>
</tr>
<tr>
<td>SSA</td>
<td>Smallholder</td>
<td>54.86</td>
<td>37.89</td>
<td>16.97</td>
<td>3.13</td>
<td>37</td>
<td>53</td>
<td>31</td>
<td>41</td>
<td>0.04</td>
<td>4.22</td>
</tr>
<tr>
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<td>Smallholder</td>
<td>96.68</td>
<td>72.84</td>
<td>23.85</td>
<td>6.31</td>
<td>41</td>
<td>24</td>
<td>51</td>
<td>69</td>
<td>0.05</td>
<td>0.98</td>
</tr>
<tr>
<td>SSA</td>
<td>Smallholder</td>
<td>43.40</td>
<td>36.56</td>
<td>6.84</td>
<td>2.76</td>
<td>41</td>
<td>0</td>
<td>18</td>
<td>35</td>
<td>0.70</td>
<td>0.72</td>
</tr>
<tr>
<td>SSA</td>
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<td>69.51</td>
<td>46.95</td>
<td>22.55</td>
<td>4.99</td>
<td>37</td>
<td>8</td>
<td>52</td>
<td>65</td>
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<td>0.60</td>
</tr>
<tr>
<td>SSA</td>
<td>Smallholder</td>
<td>39.70</td>
<td>29.68</td>
<td>10.03</td>
<td>3.23</td>
<td>36</td>
<td>78</td>
<td>13</td>
<td>21</td>
<td>0.03</td>
<td>1.66</td>
</tr>
<tr>
<td>SSA: South Asia / EAP: East Asia and the Pacific / SSA: Sub-Saharan Africa / LAC: Latin America and the Caribbean / EECA: Eastern Europe and Central Asia / MENA: Middle East and North Africa</td>
<td></td>
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</tr>
</tbody>
</table>

#### Notes:
54: Dualistic
55: Rice-wheat
56: Highland temperate mixed
57: Root crop
58: Pastoral
59: Subtotal
60: Asia
61: Dryland mixed
62: Highland mixed
63: Rice-wheat
64: Temperate mixed
65: Subtotal
66: West Asia, North Africa, Central Asia
67: Dryland mixed
68: Highland mixed
69: Rice-wheat
70: Temperate mixed
71: Subtotal
72: Subtotal for sub-Saharan Africa, Asia & OWANA
73: Latin America
74: Maize-beans (Mesoamerica)
75: Dualistic
76: Rice
77: Lowland rice
78: Subtotal
79: Wetland
80: Irrigated
81: Subtotal
82: Grand Total

Note: (BARLEY, MILLETS, AND SORGHUM).

Data are based on farming systems described by Dixon et al. (2001), poverty data from Wood et al. (2010), and crop distribution maps from You et al. (2000).
APPENDIX 5: LETTERS OF SUPPORT (ADDITIONAL LETTERS FORTHCOMING)

Montpellier, 13 April, 2011

Dr David Hoisington
Deputy Director General for Research
International Crops Research Institute
for the Semi-Arid Tropics (ICRISAT)
Patancheru, India

Subject: CIRAD’s letter of support to the CRP 3.6 “Dryland cereals: Food security and growth for the world’s most vulnerable poor”.

Dear Dave,

We are writing to confirm CIRAD and IRD’s strong interest in supporting, and actively participating as research partners, in the CRP 3.6 “Dryland Cereals”.

As you know, Cirad and IRD have a long standing tradition of collaboration with CGIAR centers involved in the CRP 3.6 -- in particular with ICRISAT in West Africa and with ICARDA in the Mediterranean region. We also participated actively in the implementation of the CGIAR Generation Challenge Program, (GCP) from the beginning. We trust the CRP 3.6 will be a new opportunity to further strengthen this fruitful collaboration and to contribute together to the fight against hunger and poverty.

As we already specified CIRAD’s teams are most interested by research on sorghum when IRD’s research work on dry cereals focus more specifically on millet.

We are enthusiastic about participating in this global initiative and, with our human resources and scientific platforms, we would be happy to be involved in the further development and implementation of this important programme.

Yours sincerely,

Patrick Caron
Deputy Director
for Research & Strategy
CIRAD

Bernard Dreyfus
Deputy Director Director for Science
IRD