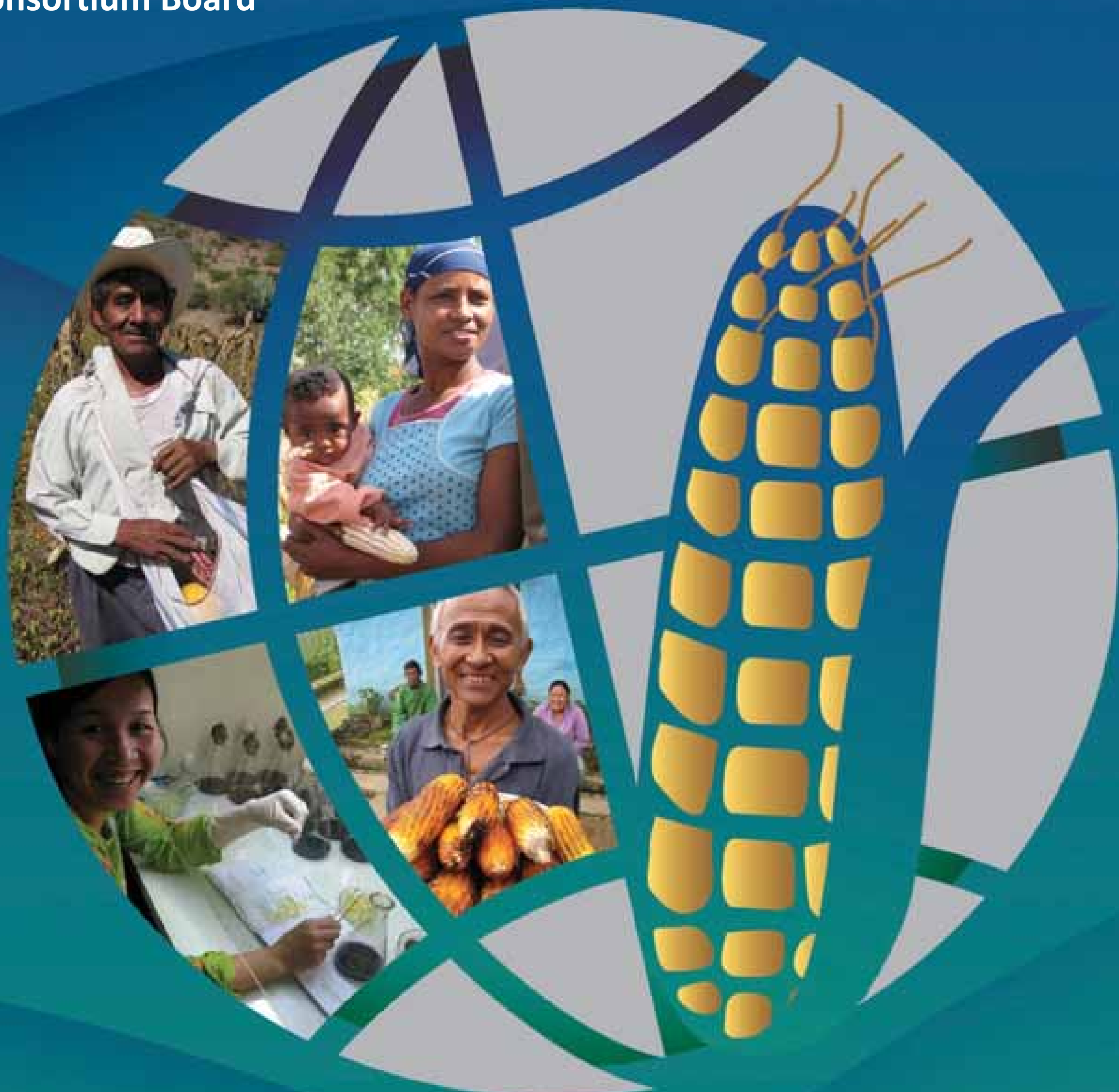
MAIZE - Global Alliance for Improving Food Security and the Livelihoods of the Resource-poor in the Developing World

Proposal submitted by CIMMYT and IITA to the CGIAR Consortium Board



In collaboration with

CIAT, ICRISAT, IFPRI, ILRI, IRRI, the World Agroforestry Centre

130 National Agricultural Research Institutes • 18 Regional and International Organizations • 21 Advanced Agricultural Research Institutes • 75 Universities • 46 Private Sector Organizations • 42 Non-Governmental Organizations and Farmer Cooperative Organizations • 11 Countries hosting MAIZE offices

1 June 2011

CIMMYT
International Maize and Wheat Improvement Center

IITA
Research to Nourish Africa

Dear Members of the CGIAR Consortium Board, ISPC and Funding Community:

Rice, wheat and maize are the most important food crops in developing countries. Addressing the challenges facing the productivity of these crops is vital to the futures of hundreds of millions of people and at the center of global agricultural development policy.

The world is clearly in the midst of an extended global food security crisis. CIMMYT and IRRI have successfully faced such challenges before, through the Green Revolution. Now the CGIAR must lead a second Green Revolution that is far more technologically advanced and which must be extended to all of Africa, Asia, the Middle East, Latin America, and beyond.

Assessing the impact of investment in agricultural development is difficult. It is difficult only because the impact can be huge; just the value of increased production resulting from such investment is so high that it distorts normal measures of investment performance. When added to other expected impacts that cannot be measured in dollars and cents—slowing rural flight, increasing human dignity and self-reliance, improving the health of women and children, saving lives—the benefits of these programs are enormous.

At the same time, the current cost to fund CGIAR research is incredibly low. Considering the present food crisis and the more than 1 billion classified as hungry, the argument that more resources for world agricultural development are not justified is morally and ethically wrong. At these costs and with these impacts, there are few investments, if any, that make more economic and humanitarian sense.

Together with IITA and many public and private partners, CIMMYT is ready and able to produce the impacts described in these documents; we must do so, and will do so. We seek to do so with the support of a strong, efficient and focused CGIAR Consortium.

Thank you for considering this MAIZE CRP submission. We look forward to discussing it with you in the coming weeks.

Sincerely yours,

Thomas A. Lumpkin

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Director General

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CIMMYT

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Abbreviations[1]

AFLP	Amplified fragment length polymorphism
CA	Conservation agriculture
CBO	Community based organization
CEO	Chief executive officer
CGIAR ADE	CGAIR alliance deputy executive
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CRP	CGIAR Research Program
CWANA	Central and West Asia and North Africa
DArT	Diversity Arrays Technology
DH	Doubled haploid
DNA	Deoxyribonucleic acid
DTMA	Drought Tolerant Maize for Africa (project)
E & SE Asia	East and South East Asia
EAP	East Asia and Pacific
EECA	Eastern Europe, Central Asia
FAO	Food and Agriculture Organization of the United Nations
GBS	Genotyping by sequencing
GCP	Generation Challenge Program
GEBV	Genomic estimated breeding value
GHG	Greenhouse gases
GIBS	Genomics and Integrated Breeding Service
GIS	Geographic information system
GM	Genetically modified
GRiSP	Global Rice Science Partnership
GS	Genomic selection
ICARDA	International Center for Agricultural Research in Dry Areas
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and communications technology
IFPRI	International Food Policy Research Institute
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IMIC	International Maize Improvement Consortium
IP	Intellectual property
IPG	International public good
IRRI	International Rice Research Institute

[1] Most institutional abbreviations are listed in Annex 2

IWMI	International Water Management Institute
KPI	Key performance indicator
LAC	Latin America and the Caribbean
mmt	Million metric tons
MoA	Ministry of Agriculture
mt	Metric tons
NAES	National agricultural extension system
NARES	National agricultural research and extension system
NARS	National Agricultural Research System
NGO	Non-governmental organization
OPV	Open-pollinated variety
PPP	Public-private partnership
pro-V A	Pro-vitamin A
PSM	Propensity score matching
QPM	Quality protein maize
QTL	Quantitative trait loci
R&D	Research and development
RDD	Research, development, and deployment
SA	South Asia
SI	Strategic Initiative
SME	Small and medium sized enterprise
SMS	Short message service
SNP	Single-nucleotide polymorphism
SRF	Strategy and Results Framework
SSA	Sub-Saharan Africa
SSR	Simple sequence repeat

Executive summary

Recurrent food price crises—combined with the global financial meltdown, volatile energy prices, natural resource depletion, and climate change—threaten the livelihoods of millions of poor people. Together with rice and wheat, maize provides at least 30% of the food calories of more than 4.5 billion people in 94 developing countries. They include 900 million poor consumers for whom maize is the preferred staple, 120 -140 million poor farm families and about one-third of all malnourished children. Between now and 2050, the demand for maize in the developing world will double, and by 2025 maize will have become the crop with the greatest production globally and in the developing world. But harvests at current levels of productivity growth will still fall short of demand and millions of farm families will remain in poverty. Unless vigorous measures are taken to stabilize food prices, accelerate yield growth, increase incomes from more productive, sustainable and resilient maize based systems, and give greater opportunities to women and young adults, the outcome will be less affordable food for millions of poor maize consumers, continuing poverty and childhood malnutrition, deforestation, soil degradation, reduced biodiversity, and accelerated depletion of water and fertilizer reserves.

This challenge is the main reason that the CGIAR centers engaged in maize research, together with a community of over 350 public- and private-sector partners worldwide, are implementing a new strategy for international maize research. The strategy is designed to ensure that publicly-funded international agricultural research helps most effectively to ***stabilize maize prices and double the productivity of maize-based farming systems, making them more resilient and sustainable and significantly increasing farmers' income and livelihood opportunities, without using more land and as climates change and fertilizer, water, and labor costs rise.*** The strategy will support and greatly strengthen the efforts of national governments, the private sector, international, regional and local organizations, and farming communities, creating or capitalizing on synergies and building on the different skills, knowledge, and resources of the community that designed the strategy.

For 900 million farmers and consumers in low- and middle-income countries, maize is a preferred crop or food. Well over 90% of resource poor maize farmers and consumers live in tropical and subtropical areas of Africa, Asia, and Latin America. The **first target group** for MAIZE world-wide is **smallholders** who live **in stress-prone environments and who have poor market access** (typically both factors go together). This group includes an estimated 640 million poor people who live on USD 2 per day or less; 275 million are maize dependent and 72 million of those are malnourished children. The **second target group** comprises **market-oriented smallholders in more favorable production areas** and with great potential to supply markets but who lack access to appropriate technology. This group includes 470 million poor, of whom 367 million are maize dependent and among whom there are at least 49 million malnourished children. Beyond these two target groups, there will be spill-over benefits to other farmers in developing countries. The third target group includes poor maize consumers and governments in low and middle income countries affected by maize price fluctuations.

At the core of the strategy are nine **Strategic Initiatives** (SIs)**.** Of high priority for international maize research and reflecting partners' feedback, the SIs are designed for integrated implementation to

generate products and services that meet the needs and aspirations and leverage the capacities of regional and local research and development partners and smallholder farmers in the above-mentioned target groups, in particular women and young adults. Their titles and main outputs are listed below:

SI 1 Socioeconomics and policies for maize futures. Increased effectiveness and positive impacts of maize research on food security, poverty reduction, gender equity, and the environment through an improved understanding of maize price developments and better targeting of new technologies, policies, strategic analysis, and institutional innovations.

SI 2 Sustainable intensification and income opportunities for the poor. Sustainable intensification and income opportunities in six maize-based farming systems where 315 million of the poorest and 22% of all malnourished children live.

SI 3 Smallholder precision agriculture. Crop management advice and practices that allow 20 million information-constrained smallholders to close the maize yield gap, lower production costs, and reduce agriculture's environmental foot print, especially through more efficient fertilizer use.

SI 4 Stress tolerant maize for the poorest. Stress tolerant maize varieties that reduce hunger and production shortfalls for 90 million people as climates change and abiotic and biotic stresses become more frequent, widespread, and intense.

SI 5 Towards doubling maize productivity. Public-private partnerships with the local seed sector and agroindustry to provide better adapted and diverse maize hybrids to smallholders in emerging markets, allowing them to produce enough maize grain to meet the daily requirements of 160 million consumers while strengthening the local breeding sector.

SI 6 Integrated postharvest management. Integrated approaches to improve food safety and reduce post-harvest losses of grain.

SI 7 Nutritious maize. Bio-fortified maize varieties that, together with outputs from SI 6, will allow heavy consumers of maize in 15 countries to attain healthy and nutritious diets and farmers to benefit from marketing opportunities.

SI 8 Seeds of discovery. Cutting-edge research to open the "black box" of maize genetic diversity, permitting researchers to mobilize its full potential in breeding programs worldwide, especially for hard-to-solve problems related to climate change.

SI 9 New tools and methods for NARS and SMEs. Novel tools to give small- and medium-scale public and private seed enterprises in developing countries the same tools as multinational ones, so that they can fill demand niches not attended by those, especially for smallholders.

All SIs include **capacity building** to empower a new generation of women and men scientists in the range of topics covered.

With a targeted annual budget rising to USD 97.8 million—to which the CGIAR currently contributes approximately 19% of the funding through unrestricted support, and bilateral CGIAR and non-CGIAR donors contribute approximately 53% of the funding through over 100 individually designed projects—MAIZE will increase the productivity of the target groups by 7% by 2020 and 33% by 2030, adding an annual value of USD 2.0 billion by 2020 and 8.8 billion by 2030. It will reach 40 million smallholder farm family members by 2020 and 175 million by 2030, and provide enough maize to meet the annual food demand of an additional 135 million consumers by 2020 and 600 million by 2030.

MAIZE will be implemented by the same community of traditional and newer partners who developed the strategy, that is:

- The principal research partners: lead center CIMMYT and IITA.
- CIAT, ICRISAT, IFPRI, ILRI, IRRI, and the World Agroforestry Centre.
- 130 national agricultural research institutes.
- 18 regional and international organizations.
- 21 advanced agricultural research institutes.
- 75 universities in developing and developed countries.
- 46 private sector organizations.
- 42 non-government organizations and farmer associations.
- 11 country governments that host MAIZE offices.

As the strategy is implemented, other principal research partners will join in managing MAIZE, from among those who contribute most in research staff and skills, infrastructure and financial resources, and whose goals are aligned with those of MAIZE.

MAIZE outputs and work of co-funded and cooperative endeavors will contribute to and benefit from other CGIAR Research Programs (CRPs). These are CRPs 1.1 and 1.2 (Integrated agricultural systems for the poor and vulnerable - dry areas and humid tropics); CRP 2 (Policies, institutions and markets for enabling agricultural incomes for the poor); GRiSP (The global rice science partnership – a part of CRP 3); CRP 4 (Agriculture and improved nutrition for health); CRP 5 (Durable solutions for water scarcity and land degradation); and, especially, CRP 7 (Climate change agriculture and food security).

Humanity faces tremendous challenges to food security and environmental degradation that will worsen if no measures are taken. Given the time needed to create the improvements described, we must act now so that poverty and hunger can be reduced, human health and nutrition improved, and better care taken of resources to support future generations.

A major maize initiative

The recent food crisis—combined with the global financial crisis, volatile energy prices, natural resource depletion, and emerging climate-change issues—undercuts and threatens the livelihoods of millions of poor people and destabilizes the economic, ecological, and political situation in many developing countries. Progress in achieving the Millennium Development Goals (such as halving hunger and poverty by 2015) has been delayed significantly; in fact, as the Food and Agriculture Organization of the United Nations (FAO) reports, the number of undernourished people actually increased in the past two years (von Braun et al., 2010).

MAIZE is part of a concerted effort of the Consultative Group on International Agricultural Research (CGIAR) to implement a new results-oriented strategy through a set of CGIAR Research Programs (CRPs) that fully exploit the potential of international agricultural research for development to enhance global food security, reduce poverty, and sustain the environment. Building on the input, strength and collaboration with over 300 partners, MAIZE will combine the strength of farming communities, international and local public and private sector partners, policy makers, and development organizations—to ensure that the CGIAR's maize-research related contribution effectively contributes to the following **Vision of Success**:

1. Increasing demands for food are met, and food prices are stabilized at levels that are affordable for poor consumers.
2. Farming systems are more sustainable and resilient, despite the impacts of climate, and their dependence on irrigation and increasingly expensive fertilizers is reduced.
3. Increased production in developing countries is achieved mainly through higher yields, thus lessening pressure on forests, hill slopes, and other crops.
4. Poverty and malnutrition are reduced, especially among women and children, and a greater proportion of women and young adults are able to engage in profitable and environmentally-friendly farming.
5. Developing countries are able to compete more vigorously in export markets and ensure benefits for a wide range of actors in the value chain of major food crops.
6. Disadvantaged farmers and countries gain better access to cutting-edge proprietary technologies through innovative partnerships, in particular with advanced research institutes and the private sector.
7. A new generation of scientists and other professionals is guiding national agricultural research across the developing world and working in partnership with the CGIAR, the private sector, policy makers and other stakeholders to enhance efficiency and impact.

Together with rice and wheat, maize provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries (von Braun et al. 2010). The combined challenges of increasing demand, continuing poverty and malnutrition, natural resource depletion and climate change will require the world to double the productivity and significantly increase incomes and livelihood opportunities from more productive, resilient and sustainable maize-based farming systems—employing essentially the same land area while contending with climate change and rising costs of fertilizer, water, and labor.

At the same time, millions of poor farm families in maize-based systems need access to livelihood strategies that increase and stabilize their incomes and provide greater opportunities to women and young adults. This challenge can only be met through a concerted effort of public and private sector partners that intrinsically involves target communities and national governments in designing appropriate solutions. Such an effort is an essential response to repeated calls for coordinated international action to achieve global food security and poverty reduction, such as the L'Aquila Joint Statement made in July 2009 by leaders of the world's largest economies.

Challenges to global maize production

Between now and 2050, the demand for maize in the developing world will double and, by 2025, it will have become the crop with the greatest production globally and in the developing world (Rosegrant et al. 2008). But harvests at current levels of productivity growth will still fall short of demand; unless vigorous measures are taken to accelerate yield growth, the outcome will be less affordable food for millions of poor maize consumers, continuing childhood malnutrition, deforestation, soil degradation, reduced biodiversity, and accelerated depletion of concentrated fertilizer reserves.

Ongoing poverty and inequity

Maize is currently produced on nearly 100 million hectares in 125 developing countries and is among the three most widely grown crops in 75 of those countries (FAOSTAT 2010; Figure 1). About 67% of the total maize production in the developing world comes from low and lower middle income countries; hence, maize plays an important role in the livelihoods of millions of poor farmers. They grow maize for food, feed, and income in 24 diverse and mostly rainfed farming systems, accounting for about 90% of the total area (Annex 1). They are often too poor to afford irrigation and are exposed to significant risks of production and income failure.

So it is not surprising that one-third of all malnourished children are found in systems where maize is among the top three crops (Hyman et al. 2008)[2]. Often with few other income opportunities than their farmstead, these farmers need options to increase and stabilize incomes from more productive, resilient and sustainable farming approaches that are adapted to future climates. Women play a significant role in maize production and maize-based systems. They need to be better involved in the design of appropriate interventions, and be given access to resources and information that allow them to improve the livelihood of their family.

[2] While a large number of poor live in maize-based systems, the relationship with malnourished children is to be understood as poverty (not maize) causing the malnutrition. Indeed, the higher the relative maize area in a farming system, the lower the number of poor and the lower the number of malnourished children (Annex 1).

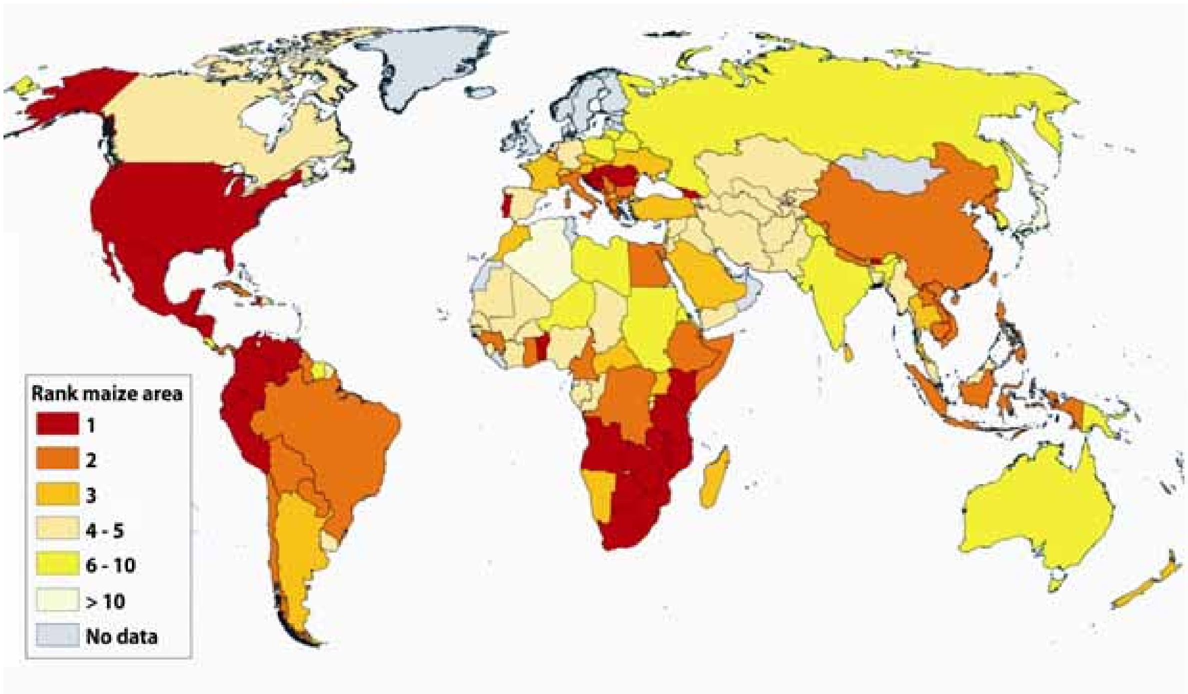

Figure 1. Relative rank of maize by area sown worldwide.

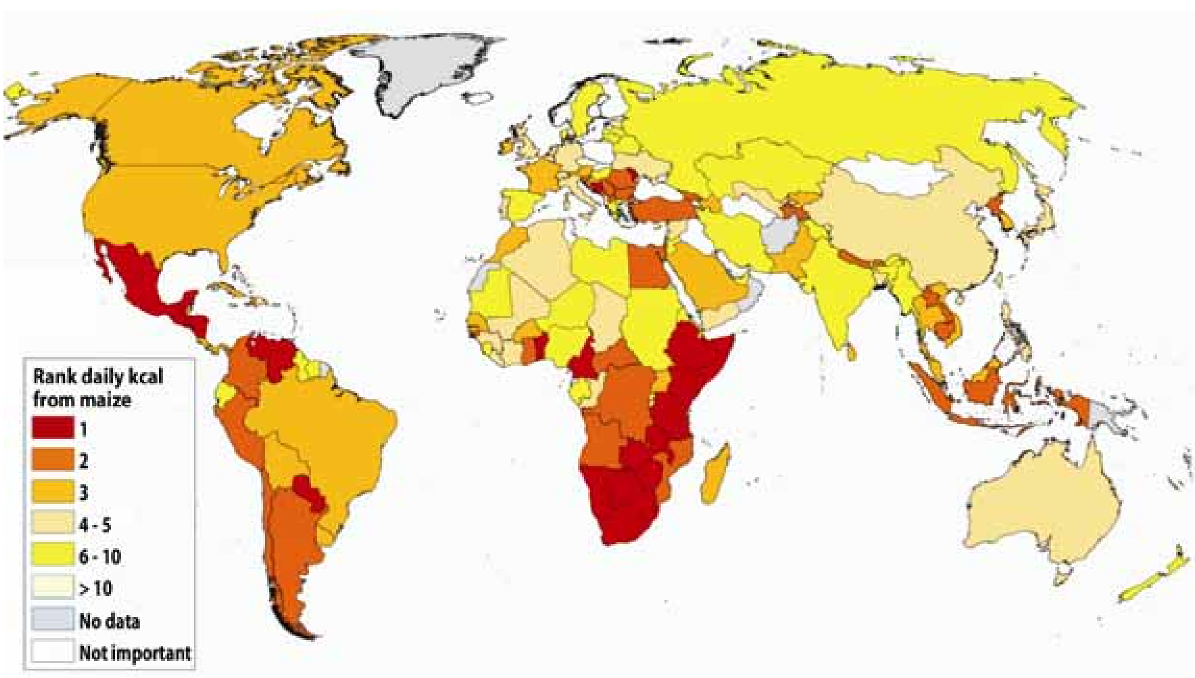

Figure 2. Relative rank of maize as a food crop worldwide.

Competing uses for a staple grain

Affordable food is among the most basic human rights, and in that respect, maize is critical, ranking third after rice and wheat as a source of calories in the diets of developing country populations (FAOSTAT 2010). Cheaper than either of those grains, maize is especially important for more than 900 million low-income consumers[3] who live in African, Asian, and Latin American countries where maize is among the three most important food crops (Figure 2).

Over the past decade, rapid economic growth in highly-populated regions in Asia, the Middle East and Latin America has increased demand from more affluent consumers for poultry and livestock products. Maize grain is a key ingredient in animal feeds, and the added demand has driven up maize grain prices and made it less affordable for poor consumers. The maize feed market is growing especially fast in countries like China and India, where economic growth is enabling many to afford milk and meat. Rapid development in those countries is also driving up demand for maize as an industrial raw material, including use for biofuel.

The market is responding, to the detriment of the environment

Farmers, governments, and input suppliers have responded to the expanding demand for maize. During 2003–08 maize production increased annually by 6.0% in Asia, 5.0% in Latin America, and 2.3% in sub-Saharan Africa (FAOSTAT 2010). Nonetheless, the increases fell short of what was needed to prevent price hikes in 2008.

Part of the response to demand has involved bringing new land into cultivation, increasing maize area in Asia and Latin America by 3.5% annually (FAOSTAT 2010, referring to data from 2003–08). But FAO estimates that only 12% of the future increase in arable land in developing countries can be achieved through area expansion without exacting unacceptably high environmental costs (Bruinsma 2009). At the current rate of area expansion, maize will eat up “its share of land” in less than five years; henceforth, maize expansion will come at the cost of crop diversity, forests, and erodible hill slopes.

A significant portion of the production increases is driven by government fertilizer subsidies, rather than by farmers adopting more sustainable and efficient practices. This has led to wasteful use of fertilizer. Expanding production through subsidized fertilizer has a frightening consequence if one considers that fertilizer prices are expected to increase strongly over the next two decades, as concentrated reserves become depleted (Cordell et al. 2009) and fuel prices increase. If fertilizers are not used more effectively and governments are no longer able to sustain fertilizer subsidies, the world will see food prices escalating much more drastically in the 2020–30s than is currently the case. Fruits and vegetables, together with maize, rice, and wheat share almost equal use of three-quarters of all fertilizer applied (Heffer 2009). Implementing more (or less) effective practices in these crops will have large effects on fertilizer reserves, environment pollution and soil depletion.

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[3] Number of poor earning less than USD 2 per day (Population Reference Bureau 2010; Worldbank 2010).

Market responses and climate change are endangering the poor

Production shortfalls in global maize supplies and increasing input prices have grave consequences for developing countries. Along with prices of other commodities, maize prices have more than doubled over the past 10 years (Index mundi 2010) and may do so again by 2050. Such increases will impose great hardships on the poor, as the food price surges of 2008 and 2010/2011 made abundantly clear. In addition, lagging domestic production will place a huge and politically risky burden on developing country economies, driving up their maize imports from 5% of today's demand to 24% in 2050, a proportion that will be priced at around USD 30 billion (Rosegrant et al. 2008).

Even more worrisome, events between 2008 and 2011 showed that food price developments are much more complex than had previously been assumed. Global food price changes are affected by energy prices, through their impact on input prices and increasing demands for biofuels, and increasingly by production conditions and profitability assessments of crops in a relatively small number of global "bread baskets." Moreover, traditional market behavior may have been derailed by the speculative decisions of millions of financial market participants and panic responses of governments with inadequate access to accurate production and demand information. Maize prices in 2011 were already as high as had been previously predicted for 2050, based on long-term supply/demand projections.

Markets lack transparency due to inadequate production/stock/demand estimates and high private sector involvement. Actual or perceived physical stocks have fallen so much that even relatively small production fluctuations cause major price fluctuations. Nearly 60% of global maize production comes from just two countries—the USA, China—even while maize figures among the top three food staples in 56 low- and middle-income countries. Poor harvests in a major US or Chinese breadbasket have caused much of the production variation in the past (Figure 3); with depleted global stocks, such perturbations could imply political turmoil for many maize-importing countries. It seems that the realities of financial markets and human behavior have overtaken the economic ideals of comparative advantage and unfettered international trade. An excessive focus on a few breadbaskets has exposed us to an inacceptable risk that affects the poor and political stability.

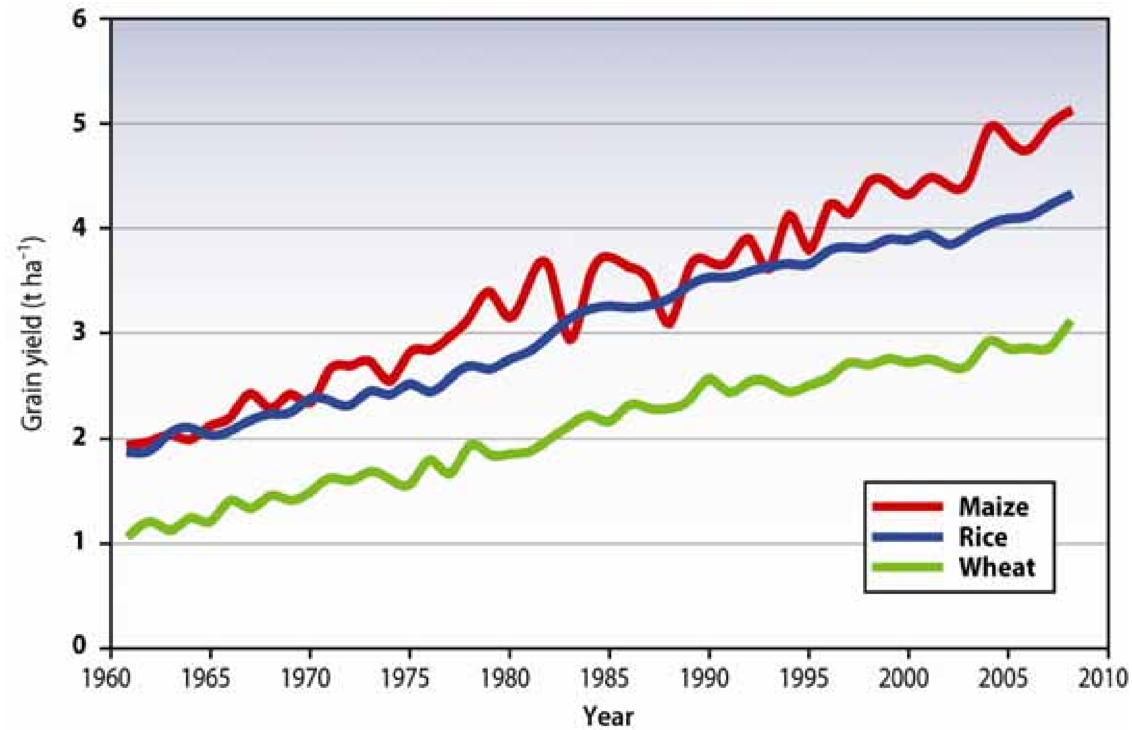

Figure 3. Annual global yield fluctuations of rice, wheat, and maize, 1961–2008.

Low and middle income countries will also be those most affected by climate change. Spatial analyses in recent years have consistently predicted an average 10% decline in maize yields by 2050 for sub-Saharan Africa and Latin America (Thornton et al. 2009). A recent study showed much stronger heat impacts on maize than previously assumed (Lobell et al. 2011). For Africa particularly, the impacts will be highly variable, with southern African maize crops suffering the worst damage, while regions like the East African highlands may see improved maize production. The challenge will be to provide maize farmers with the means to respond to both climate change threats and opportunities.

One expected threat of climate change is more frequent and severe droughts. With most maize production dependent on rainfall, the crop is particularly vulnerable to drought and its yields fluctuate more widely from year to year than is the case for rice and wheat, which are more commonly irrigated (Figure 3). Production fluctuations—whether local, regional, or global—give rise to price hikes and food shortages. Already now, the probability of failed seasons in farming systems where maize is among the three most important crops varies between 8 and 35% (Hyman et al. 2008). As irrigation costs increase and land gets scarcer, many Asian farmers are switching from irrigated wheat and rice to maize, grown under reduced irrigation or rainfed conditions.

A new strategy for international maize research

The combined challenges of increasing demands, continuing poverty and malnutrition, natural resource depletion and climate change will require the concerted engagement of farming communities, international and national researchers, policy makers, the private sector, and many other development partners. In regard to maize, their shared challenge is to ***double productivity and significantly increase the incomes and livelihood opportunities from more productive, resilient and sustainable maize-based farming systems on essentially the same land area—while contending with climate change and increasing costs of fertilizer, water, and labor.***

Success among the concerted investment of partners—at international, regional and bilateral level, and by the public and private sector—will imply that the following **impact targets** are being met:

1. As compared with current trends, boost maize productivity by at least *an additional* 20% by 2020 and 50% by 2050 in 60 major maize-producing countries of the developing world, thus helping ensure accessible and stable prices for the over 900 million poor maize consumers.
2. Sustainably intensify maize production and ensure stabilization of the total maize area at about 120 million hectares in developing countries, thus avoiding environmental damage.
3. Reduce the frequency of production shortfalls and price volatility in areas and countries where the probability of crop failure in maize-based farming systems is greater than 15%.
4. Diversify maize-based farming systems and enhance their productivity and sustainability, dealing specifically with the systems with the highest poverty concentrations, where over 660 million maize-dependent poor and about 62 million malnourished children live.
5. Ensure that higher rates of maize yield growth are sustained beyond 2020 in the face of climate change impacts, worsening water scarcity, and rising fertilizer prices.
6. Increase opportunities for diverse market participation, including locally emerging companies, women and young adults, and give developing countries access to know-how and technologies comparable to those available in high-income countries.

To clarify the role of international maize research, CIMMYT(www.cimmyt.org) and the International Institute for Tropical Agriculture (IITA www.iita.org), i.e. the two CGIAR centers most prominently engaged in international maize research, have been consulting widely over the last three years. This has happened in the frame of maize research consortia and integrated projects in Africa, Asia and Latin America—including stakeholders in some 30–40 target countries—as well as through discussion of coordinated workplans, new projects and memoranda of agreements with ministries of agriculture and national agricultural research institutes in major maize-producing countries, regional organizations and major institutional partners from the public and private sector (Annex 2).

Recognizing current strengths in maize germplasm development and multi-institutional partnerships, stakeholders requested that international maize research adopt a relatively increased emphasis on agronomy and post-harvest issues, strike a better balance between maize farming systems and maize commodity work, and provide guidance for using upstream state-of-the art biotechnology and bioinformatics tools in applied maize breeding programs while continuing investments in stress environments and capacity building. It was emphasized that research and capacity-building efforts need to be well balanced between a household food security focus, on one hand, and productivity enhancement, on the other, so to increase farmers' incomes while meeting national and consumer demands. As well, international maize research investments in disadvantaged regions in Asia and Latin America need strengthening, given recent under-investments, and interventions need to achieve a five-fold goal: greater productivity, greater farm-level incomes, greater resilience in relation to price and climate risk, more sustainable production in view of costly and limiting inputs and environmental degradation, and capacity building.

The results of these discussions led to the definition of MAIZE, i.e. a new strategy for international maize research. It is formulated as a set of Strategic Initiatives through which publicly-funded international maize research is likely to contribute most effectively in achieving the grand challenge and impact targets, while complementing and adding value to approaches implemented by national governments, the private sector, and other international, regional and local organizations. The relative emphasis for implementing Strategic Initiatives varies between Africa, Asia and Latin America, and these differences will be captured and considered in the execution of MAIZE.

The execution of MAIZE builds on strong, on-going and evolving collaboration of CIMMYT and IITA with over 300 partner institutions. Currently they include CGIAR centers and Challenge Programs, national agricultural research systems (NARSs), universities in the South, national agricultural extension systems (NAESs), advanced research institutions from North and South (ARIs), national non-government organizations (NGOs), international non-government organizations (INGOs) and private companies. They are individually listed in Annex 2, and new partners are expected to join.

Memoranda of Agreement and workplans that formalize engagement in the international maize research and development agenda have been established with over half of these partners and build upon detailed workplans mostly within highly multidisciplinary and multi-institutional projects, such as: the Drought Tolerant Maize for Africa project; the Sustainable Intensification of Maize-Legume Systems in eastern and southern Africa; the Cereal Systems Initiative in South Asia; upstream collaboration with multinational private companies, advanced research institutes, and the Generation Challenge Program on molecular, transgenic and bioinformatics approaches; mycotoxin and post-harvest pest research in eastern, west and southern Africa; the development and promotion of protein- and micronutrient-enhanced varieties in Latin America, Africa and Asia.

The concept of Strategic Initiatives allows clustering these activities around priority interventions, implementation of more streamlined partnership approaches, and conclusion on funding gaps *versus* priorities expressed. Implementation of the Strategic Initiatives will be driven by regional priorities and needs, and take place in collaboration with local partners engaged in relevant value-chain components while drawing on international expertise where applicable.

Target beneficiaries

The target beneficiaries of MAIZE are resource-poor farmers and consumers in low- and middle-income countries for whom maize is a preferred crop or food, with focus on the disadvantaged.

In order to be more effective and focused, MAIZE will particularly target two types of farmers and their service providers (such as researchers, technology and information providers and policy makers):

- Target Group 1: Smallholders in stress-prone environments with poor market access;
- Target Group 2: Market-oriented, technology-constrained smallholders in more benign environments.

These two target groups live in farming systems that occupy approximately 64% of all maize by area in the developing world and are home to 1.2 billion of the poor and 126 million malnourished children—nearly seven-tenths of the world's total (Table 1). The other 36% of the maize area is cropped by wealthier, commercially oriented farmers, or smallholders that live interspersed in areas of large commercial farming and benefit from private sector investment in these areas.

The two target groups were identified systematically by taking all the rainfed farming systems in the tropics and sub-tropics that include at least 1 million hectares of maize (Dixon et al. 2001) and where the majority of farmers are smallholders. “Maize-dependent poor”—defined as the number of poor depending on an area equivalent of 25% maize, as well as their exposure to drought stress in maize—were identified by superimposing analyses of Hyman et al. (2008) and others (Annex 1). The following section describes in more detail each of these groups. Data for them are summarized from Annex 1 in the top half of Table 1, including a list of the farming systems and regions in which they live. The lower half of Table 1 identifies the main objectives relevant to the two target groups in each of the Strategic Initiatives.

Target Group 1: Smallholders in stress-prone environments with poor market access
Farmers in stress-prone or outlying areas—often both go together—are among the poorest, with low purchasing power, frequent food deficits, and the most severe malnutrition in children. Annual production fluctuates through drought and other stress factors, while under-developed markets contribute to high price variation and food and income insecurity. There are an estimated 640 million two-dollar-a-day poor people in the farming systems comprising this target group; an estimated 275 million of these are maize-dependent, and they include also at least 72 million stunted children. The farming systems are located in South Asia, sub-Saharan Africa, and Latin America & the Caribbean. Many are in the poorest countries that have weak national research systems and the least-developed private sector.

Target Group 1 needs comprehensive solutions that link maize-based interventions with those for accompanying crops and livestock, increase the productivity and resilience of the farming systems, and attempt to link farmers to viable markets for inputs and surplus products. Relevant interventions for this target group include stress-tolerant varieties of maize and other crops that stabilize and increase production even as climates change, as well as sustainable crop management approaches that increase productivity while reversing widespread soil degradation. These interventions need to be aligned with more profitable value chains, include risk management strategies, and allow farmers to accumulate assets. Value chains in stress-prone and outlying environments are often weak and need to be developed. Research, extension, input supply and markets responsive to farmers needs—in both public and private sectors—need to be strengthened. Efforts should particularly focus on empowering women and young adults, the population segments that hold the greatest leverage for development.

Target Group 2: Market-oriented, technology constrained smallholders in more benign environments
There are many smallholder farmers who benefit from adequate market access but lack the technologies or know-how to optimize their production systems. They have a strong opportunity to increase maize productivity and stabilize maize prices for urban and rural consumers as well as providing income for themselves. Especially since grain prices are increasing, they are avid to obtain better varieties and farming practices.

Private research providers show little interest in this group because market size and margins are either too small or suitable technology would be expensive to develop compared with high-margin markets in irrigated areas or other areas favored by commercial farmers. Also, two decades of significant underinvestment in agronomy research and extension have left large human resource and knowledge gaps in public research and extension systems that translate into significant information gaps for this target group. This target group comprises an estimated 470 million two-dollar-a-day poor people, of whom the vast majority (367 million) is maize-dependent. There are also at least 49 million stunted children. These systems are located in East Asia, South Asia, sub-Saharan Africa, and Latin America & the Caribbean.

To boost production significantly among this group of farmers, NARSs, NAESs and local seed companies—which are willing to enter areas that are unattractive to multinational companies—could be empowered by MAIZE to use cutting-edge tools to develop locally-adapted varieties. They could also be aided in applying precision agriculture methods and modern communication technologies to identify and rapidly scale out best practices.

Spill-over benefits: Smallholder commercial farmers and large commercial farmers
Farming systems not included in Target Groups 1 and 2 are dominated by larger-scale commercial farmers or are in temperate maize zones. They are generally well served by private companies and strong national research programs from which smallholders in these areas also benefit. Even though sowing 36% of all maize areas, these farming systems are populated by less than 10% of all two-dollar-a-day poor (70 million), maize-dependent poor (66 million) and stunted children (at least 5 million). This group will benefit from spillovers from MAIZE through NARSs and private companies that use and adapt R&D products targeted at the other farming systems.

Table 1. Impact domain for two target groups, and main objectives of MAIZE Strategic Initiatives.

	Target farmers		Farmers benefiting from spillovers
	Target 1. Stress-prone smallholders with poor market access	Target 2. Market-oriented, technology-constrained smallholders in more benign environments	Large and smallholder commercial farmers
Drought, nutrient and heat stress in maize	High in most areas	Drought and heat in some areas	Drought and heat in some areas
Market access	Usually poor	Good	Good
Farmer support organizations	Often weaker NARSs with fewer staff, and weakest market participants; NGOs	NARSs and local seed companies of variable strengths	Large seed companies, and commercial farmer organizations
Impact domain and its relevance for the poor			
Maize area (million ha)	> 24	> 32	> 31
People (million)	> 1,200	> 1,700	> 480
Poor in farming system (million)	640	470	90
Poor in maize area (million)	490	340	70
Maize-dependent poor (million)	275	367	66
Stunted children in farming system (million)	> 72	> 49	> 5
Farming systems EAP = East Asia and Pacific LAC = Latin America & Caribbean SA = South Asia SSA = sub-Saharan Africa EECA = Eastern Europe, Central Asia	Rainfed mixed SA; Rice–maize SA; Maize–beans (Mesoamerica) LAC, Dryland mixed LAC; Maize mixed SSA, Cereal-root crop mixed SSA; Agro-pastoral millet/sorghum SSA	Lowland rice EAP; Highland extensive mixed EAP, Upland intensive mixed EAP; Highland mixed SA; Intensive highland mixed (N. Andes) LAC, Coastal plantation mixed LAC; Root crop SSA, Tree crop SSA, Forest based SSA, Highland temperate mixed SSA	Extensive dryland mixed (Gran Chaco) LAC, Cereal-livestock (Campos) LAC, Irrigated systems Coastal plantation mixed LAC; Large commercial–smallholder SSA; Temperate mixed EAP, Pastoral EAP; Large scale cereal-vegetable EECA; Temperate mixed (Pampas) LAC
Strategic Initiatives	Main objective		
SI 1. Socioeconomics and policies for maize futures	Target interventions, design supporting policies, and strengthen value chains	Target interventions, design supporting policies, and strengthen value chains	Access to all MAIZE international public goods (IPGs)
SI 2. Sustainable intensification and income opportunities for the poor	Increase the sustainability, profitability and resilience of maize-based systems with the poorest	Less relevant to this target group	Access to all MAIZE IPGs
SI 3. Smallholder precision agriculture	Low-risk nutrient management to increase productivity and reduce soil nutrient depletion	Optimize fertilizer use and reduce the environmental footprint	Access to all MAIZE IPGs
SI 4. Stress tolerant maize for the poorest	Increase and stabilize maize productivity in stress-prone environments	Reduce large production losses from drought in higher-yielding areas	Access to all MAIZE IPGs
Si 5. Towards doubling maize productivity	Less relevant to this target group	Provide diverse and locally adapted hybrids by leveraging the capacity of NARS and local seed companies	Access to all MAIZE IPGs
Si 6. Integrated postharvest management	Safe food and grain storage options that increase food security and value	Marketing opportunities for farmers and safe food for urban consumers	Access to all MAIZE IPGs
SI 7. Nutritious maize	More nutritious food, for children in particular	Marketing opportunities	Access to all MAIZE IPGs
SI 8. Seeds of discovery	Developing the basis for sustaining maize productivity increases into the future, as climate change and land, water, and fertilizer scarcities become more pronounced		
SI 9. New tools and methods for NARS and SMEs	Accelerating breeding gains for stress-prone environments	Application by partners to accelerate breeding gains in a wide range of environments	Application by partners to accelerate breeding gains in commercial environments

Target Group 3: Poor consumers and low and middle income countries with large number of poor consumers

Recent food price developments are exposing low- and middle-income countries to a high risk of political turmoil and social instability as poor consumers are deprived of food. Many interventions will need to come from financial market stabilization and increased market transparency as defined recently by G20 member countries. Research however has to provide its own contribution. We need to better understand short- and long-term price development. This includes the risk from focusing production on a few global breadbaskets, the relationship of crop production with energy prices, changing demands (e.g., from biofuel), changing profitability assessments by farmers, and speculative and unpredictable financial markets and government policies. Much of this work will take place as part of CGIAR research program on 'Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor'. MAIZE can contribute improved production predictions, improved maize-specific models assessing climate change impacts (e.g., Lobell et al. 2011), and in general work to improve maize specific information used by CRP 2.

Summary of Strategic Initiatives

Working with the broad network of partners, MAIZE developers identified nine Strategic Initiatives to respond to the needs of the two target groups and to prepare for future research needs. The following section gives a summary of each Strategic Initiative, focusing on the partner-driven genesis, outcomes, methods and outstanding innovations. Additional background information, rationale, researchable issues, outputs and milestones, and impact assessment are provided in Section 2 of this document.

Strategic Initiative 1: Socioeconomics and policies for maize futures

Genesis with partners and justification

In a rapidly changing global economic and social situation as most prominently evidenced by recent food price developments, national, regional, and international economics researchers need to work together. This will involve understanding and regularly adjusting the framework in which MAIZE-relevant technologies, data, and know-how are developed, to effectively achieve impact targets (p. 6). Directed at maize-specific issues, this Strategic Initiative works in close interaction with CRP2, which focuses on crop generic analyses and interventions.

Outcomes

- More powerful ex-ante analysis of future outcomes, market prices, supply and demand projections.
- Increased effectiveness of maize research on food security, poverty reduction, gender equity and the environment, through better targeting of new technologies, policies, strategic analysis, and institutional innovations.
- Strategic social science information required by all other Initiatives, including MAIZE-relevant databases and GIS information.
- A concerted effort to provide greatest benefits to the resource-poor and reduce gender disparities.

Methods

- Aligned with CRP2 efforts, use agricultural market data (e.g., from the FAO-based Agricultural Market Information System, AMIS) and international remote sensing data to iteratively improve maize market outlooks and forecasts and link them with energy markets, policy monitoring, price transmission from world to domestic markets and food security assessments. Explore the relations between biofuel and food production and the resilience of maize production to price increase and volatility.
- Advanced geospatial analysis and wealth ranking tools for targeting the resource-poor and different gender groups, selectively applying a new generation of partial (e.g. multi-market models, economic surplus, IMPACT model) and general equilibrium approaches. These will allow iterative adaptation of the MAIZE agenda and a better understanding of the drivers of change (climate change, demand for livestock products, and effects on maize demand for food, feed, and other uses).
- Novel tools for market and value-chain analysis and methods for integrated economic, social and environmental impact assessment (e.g. bio-economic modeling, propensity score matching and double difference methods). These will evaluate ex-post the impacts on poverty, food security, gender and the environment.
- Qualitative tools—stakeholder analysis, outcome mapping, gender analysis and focus group discussions—to complement impact studies.

Outstanding innovations

- Increased understanding of market behavior that goes beyond agriculture production and includes the energy sector, financial markets, and risk management approaches, versus purely econometric supply-demand estimates
- Application of a new generation of partial and general equilibrium approaches for ex-ante analysis of future outcomes, market prices, supply-and-demand projections, and understanding impacts of emerging drivers (climate change, income growth, urbanization, derived demand for maize as feed and other uses).
- Explicit focus on gender effects.
- Institutional innovations that improve access to information, technologies and markets, as well as facilitating adaptation to and mitigation of climate change.
- Strategic systems analysis at the regional or farming systems levels, by obtaining data from panels, geospatial analysis and wealth ranking and linking them with market and value chain analysis.
- Integrated economic, social, and environmental impact assessment.

Strategic Initiative 2: Sustainable intensification and income opportunities for the poor

Genesis with partners and justification

This Initiative rose from partners' strong request for an integrated R&D approach between maize-based interventions and those of other crops and livestock for making a rapid and pronounced impact on poverty reduction, food insecurity, and the sustainability and resilience in maize-dominated farming systems, especially for farmers of target Group 1[4].

Outcomes

- Sustainable intensification and income opportunities for six maize-based farming systems (i.e. where maize is the dominant crop) where 315 million of the poorest and 22% of all malnourished children live.

Methods

- An innovation systems approach that seeks to optimize variety use, improved commodity mixes, more sustainable agronomic practices, and more effective use of resources—that is, labor, nutrients, land and finance.
- Institutional innovations that link farmers and producer groups to markets, credit and innovative insurance products.
- Simulation models, GIS analysis and decision tools to up-scale more successful farmer-selected innovations.
- Links with progressive farmers and stakeholders from multiple agencies that use their own networks and comparative advantages to help overcome bottlenecks and foster appropriate identification of interventions, capacity building, and rapid scaling out.

Outstanding innovations

- Integration of best-bet technological options and institutional innovations to address multiple constraints on smallholder farmers.
- Much greater attention to client-oriented development, packaging and scaling out of research outputs.
- The approach goes beyond addressing constraints in maize production; it involves farmers and value-chain participants in an innovation-systems approach.
- New information and communication technologies will permit a complete change in focus of research and technology dissemination—from general recommendations to more precise, site-efficient and timed practices.

Strategic Initiative 3: Smallholder precision agriculture

Genesis with partners and justification

This Initiative arises from the concern that many NARSs have downgraded agronomy research in the past 20 years. The Initiative aims to revitalize agronomic capability in a wide range of NARSs and NAESs, specifically tied to recent opportunities in precision agriculture and Information and Communications

[4] Based on conclusions from the meetings of the Consortium Board with the former CGIAR Alliance Executive in March and April 2010, maize-, rice-, and wheat production systems research was integrated in CRP3 (MAIZE, GRiSP and WHEAT), while CRP1 was designed to focus on poverty hotspots in more diverse systems where interventions are less likely to be aligned with interventions on one of these three major food crops.

Technology (ICT). Through international networks and approaches, these opportunities can generate and strengthen site-specific recommendations and capacities for the benefit of smallholders. Farmers in Target Group 1 benefit from risk-resilient approaches that prevent further nutrient depletion, while farmers in Target Group 2 increase fertilizer use efficiency and reduce environmental pollution during maize production.

Outcomes

- Crop management advice relevant to 20 million information-constrained smallholders to close the maize yield gap and reduce agriculture's environmental footprint.
- Results-oriented capacities for agronomy research in NARSs and NAESs.

Methods

- A wide network of international exploratory diagnostic trials, aligned by environmental and socio-economic similarities.
- Geo-referenced web-based data and low-cost remote sensing devices and approaches.
- Methods for client-oriented development, packaging and scaling out of research results through ICT technologies and local networks of stakeholders.

Outstanding innovations

- Precision agriculture approaches for smallholder maize farmers.
- Linking decision guides for farmers and extensionists to geographic and marketing information systems and to the results of the wide network of diagnostic trials.

Strategic Initiative 4: Stress tolerant maize for the poorest

Genesis with partners and justification

This Initiative builds on the stress tolerance work of CIMMYT and IITA in sub-Saharan Africa. Given the current importance of abiotic stresses and the advancing impacts of climate change, it was strongly emphasized as a priority by NARESs there, as well as in Asia and Central America. MAIZE will make it possible for the poorest countries to benefit from cutting edge research in tolerance to abiotic stress through well established (and expanding) linkages among the CGIAR, advanced research institutes and multinational private companies. Due to poor development of the seed sector in stress environments, approaches are needed that strengthen the deployment and accelerated adoption of stress-tolerant maize through the local seed sector and community-based seed production schemes, in particular in the lowest income countries.

Outcomes

Stress-tolerant maize varieties suitable for reducing hunger and production shortfalls become available for 90 million people, as climates change and the risk of drought increases. Tolerance will be to abiotic stresses prevalent in resource-constrained smallholder farmers' fields—drought, heat, water-logging and sub-optimal soil nitrogen.

Methods

- Innovative approaches to accelerate dissemination of stress-tolerant maize into areas with weaker seed value chains.
- High-precision, stage-specific phenotyping tools under managed stress, including new approaches to controlling field variation.
- Application of state-of-the-art genomic selection in doubled haploids, based on high-density, low-cost marker systems developed in SI 9—these will enhance the reliability of selection, identify new donor lines and accelerate genetic gains for stress-prone environments.
- Transgenic varieties with improved tolerance to drought and low fertility developed, tested and disseminated through well established and diverse public-private partnerships.
- Novel, low-cost hybrid seed production strategies to improve access of poor smallholders to vigorous and resilient hybrid seed—this is especially important in stress-prone environments.

Outstanding innovations

- A coordinated, inter-institutional stress tolerance screening network including biotic and abiotic stresses.
- Drought tolerance breeding will be extended from Africa to Asia and Latin America, and breeding for waterlogging tolerance will be scaled up in Asia.
- Screening for combinations of stresses—particularly drought plus low fertility (sub Saharan Africa, Central America), drought plus heat (Asia and subtropics) and drought plus water-logging (South Asia).
- A systematic public pipeline for marker development for biotic and abiotic stress tolerance genes, strengthened through partnerships with multinational seed companies and emerging biotechnology capacities in China, India and Mexico.
- Innovative seed production systems that allow small-scale seed companies to produce hybrids at low cost.
- Approaches to speed the dissemination of drought-tolerant maize into areas with weaker seed value chains.

Strategic Initiative 5: Towards doubling maize productivity

Genesis with partners and justification

After a decade of strong attention by the CGIAR to farmers in drought-affected environments, national governments raised the concern that many farmers in more favorable environments continue to have inadequate access to locally adapted improved maize varieties. Although private investments in maize breeding for subtropical and tropical areas have been increasing, they still comprise only about 5% of investments made for temperate environments. Facing the need to double maize production on a limited area, governments call for a renewed and demand-driven CGIAR maize breeding investment in favorable environments, in support of NARSs and local seed companies.

Outcomes

Public-private partnerships to generate and provide better adapted and diverse maize hybrids to smallholders in emerging markets, allowing them to produce grain that can feed 160 million people, while strengthening the local breeding sector.

Methods

- Through the International Maize Improvement Consortium, establish a demand-driven collaborative model for engaging and supporting NARSs and SMEs in delivering elite maize hybrids into more difficult-to-serve markets.
- Target smallholders in favorable growing areas not attended by the private sector (due to significant germplasm adaptation gaps or smaller-sized markets).
- Participating members of the Consortium—NARSs and local seed companies—will have privileges and obligations to receive germplasm and information.

Outstanding innovations

- A demand-driven approach that uses membership and performance contracts to improve research quality and accelerate delivery to "pre-commercial" smallholders.
- Traits associated with high yield potential and efficient input use in tropical environments will be studied through crop physiological analysis and era hybrid studies.
- State-of-the-art tools (doubled haploids, high-density marker-based genomic selection), originating from Strategic Initiative 9 (SI 9), will be applied to the improvement of yield potential and stress tolerance in higher-rainfall environments.
- Formalized intellectual property (IP) boundaries on research collaboration; each research partner can use germplasm for further proprietary development while the jointly developed germplasm remains in the international domain, for stimulating competitive market development.

Strategic Initiative 6: Integrated post-harvest management

Genesis with partners and justification

Post-harvest challenges are given very high priority by partners, in particular in eastern and southern Africa, Nigeria and Indonesia. In specific regions, 30% and more of good harvests are lost to post-harvest insect pests, robbing farmers of the opportunity to achieve food security or generate income during times of the year when grain prices increase. Mycotoxin contamination has led to severe health impacts in eastern Africa and excluded countries from the benefit of export opportunities.

Outputs and expected impacts

- Reduced post-harvest losses and mycotoxin-related health risks.
- Integrated approaches to improving food safety and reducing post-harvest losses, allowing farmers in 15 countries to attain healthy diets and benefit from marketing opportunities.

Methods

- Aggressive development, validation and promotion of low-cost technological interventions that do not rely on pesticides: storage structures, mycotoxin screening assays and biocontrol.
- Developing and deploying genetic resistance to post-harvest insect pests, ear molds and mycotoxin contamination.
- Generating awareness among stakeholders on the health risks of consuming contaminated grain.

Outstanding innovations

- GIS-based targeting of interventions to highest risk groups.
- Combining multiple resistances to post-harvest insect pests, ear molds, drought and mycotoxin contamination with introduction of low-cost storage structures and mycotoxin assaying techniques, for safe storage at the farm level.
- Biocontrol as a new tool for aflatoxin mitigation in Africa.

Strategic Initiative 7: Nutritious maize

Genesis and justification

With over one third of all stunted children living in maize-based systems, this Initiative pursues nutritional improvement opportunities for pro-vitamin A maize in Africa, and for high quality protein maize in Ethiopia, Central America and South Asia. It is closely linked to CRP 4 on "Agricultural health and nutrition".

Outputs

- Bio-fortified maize varieties, in both macro- and micro-nutrients, allowing farmers in 15 countries healthy and nutritious diets and marketing opportunities.

Methods

- Genetic discovery, rather than just using existing genes, to deal with long-term nutritional issues and opportunities.
- Molecular genetics (allele mining and marker-assisted selection) alongside conventional plant breeding.
- High-throughput phenotyping and nutrition research to assess factors influencing bioavailability.

Outstanding innovations

- Pursuit of newly-emerging transgenic opportunities for biofortification.
- Greater emphasis on specialist traits relevant to specialist high-value products for smallholders and for agro-industry.

Strategic Initiative 8: Seeds of discovery

Genesis and justification
Accelerated developments in genomics, bioinformatics and phenotyping enable scientists, for the first time in history, to begin to unlock the black box of native genetic diversity of major crops. Holding in trust the most important germplasm bank for tropical maize, MAIZE tackles this challenge in collaboration with the most advanced public and private sector institutes.

Outcomes
Enable researchers to mobilize the full potential of maize biodiversity in breeding programs worldwide. This will help speed breeding gains and enable the world community to counteract the accumulating effects of climate change and scarcities of water, land and nutrients.

Methods
- Apply next generation sequencing technologies and state-of-the-art precision phenotyping to the most relevant cross-section of native maize genetic diversity.
- Develop Web-based user-friendly platforms.
- Promote the flow of useful diversity into research and breeding programs worldwide via access to seeds of well-characterized accessions.
- Capture into elite backgrounds both large-effect QTL alleles via marker-assisted introgression and small-effect alleles via rapid-cycle genomic selection.

Outstanding innovations
- First attempt to comprehensively characterize the global heritage of maize genetic resources to promote flow of useful diversity into research and breeding programs.
- A world-first breeder- and researcher-friendly "catalog" for the CIMMYT- and IITA-held maize seed "libraries", transforming them from black box germplasm banks to accessible trait, gene and marker libraries.

Strategic Initiative 9: New tools and methods for NARSs and SMEs

Genesis and justification
New breeding tools, notably high-density genotyping, doubled haploids and improved informatics, are rapidly increasing rates of genetic gain in the breeding programs of multinational seed companies. Responding to the demand from NARSs and local seed companies, this Initiative will provide them with access to these tools to accelerate breeding progress targeted at poorer farmers. Collaborations with the multinationals and ARIs have already been developed to enable this Initiative, with CIMMYT and IITA acting as "honest brokers" that respect intellectual property and trade secrets while developing and making prioritized non-proprietary know-how and tools widely available. This Initiative aligns and often pioneers approaches that are then scaled up by the Genomics and Integrated Breeding Service (GIBS), for use by other cross-pollinated and hybrid crops with lesser importance and hence lesser investment.

Outcomes

Novel tools will empower NARSs and SMEs to accelerate breeding gains for diverse smallholder farmer groups, encompassing a wide range of needs and environments.

Methods

- Adapt high-density genotyping, doubled haploids, improved informatics and other new tools for use by small- and medium-scale seed enterprises (SMEs) and NARS breeding programs.
- Develop, test and package these tools so that they can be implemented by maize breeders in NARSs and local seed companies, and through collaboration with the GIBS, also benefit breeders of other cross-pollinated crops where similar sized investment may not be justifiable.

Outstanding innovations

- Provide the first publicly available tropical haploid inducer lines to maize breeders in Africa, Latin America and Asia.
- State-of-the-art public tools applicable to breeding programs of NARSs and local seed companies, including "open-source" designs for integrating rapid-cycle genomic selection and double haploid technology.
- The first application of genotype-by-sequencing to public maize breeding programs, and the first proof-of-concept of rapid-cycle genomic selection.

Capacity building

Genesis with partners and justification

Capacity building is vital to impact, exit strategies and long-term sustainability of the products of MAIZE. During consultations, partners repeatedly emphasized the importance of specialized training in almost all of the areas of the Strategic Initiatives—including agronomy of maize-based systems, precision agriculture, breeding for drought tolerance, post-harvest technology, and use of new tools and methods for maize breeding and seed production. They emphasized that all these were best done as an integrated part of the research partnering. As an example, a recent analysis by the Global Partnership Initiative for Plant Breeding Capacity Building (FAO 2005) highlighted the insufficient capacities in both conventional and modern plant breeding technologies in many developing countries. As a result, these countries fail to fully capture the benefits of plant genetic resources, new tools and technologies.

Outcomes

Capacity-building efforts in each Strategic Initiative will empower a new generation of women and men scientists and other professionals to reduce poverty and hunger, improve human health and nutrition and nurture the environment to support future generations.

Methods

- Collaboration with local universities and advanced research institutes through “sandwich” programs to involve graduate students from the developing world in MAIZE.
- Addressing region- and SI-specific applied training needs, by closely linking training to research efforts in each Strategic Initiative and by exploiting the involvement of advanced research institutes in various Initiatives.
- Opportunities for NARS and private-sector researchers to develop their skills through active participation in the MAIZE research program and as visiting scientists, postdoctoral research fellows and postgraduate students.
- Preferential access to training opportunities for women and young researchers.

Interrelationship and management of Strategic Initiatives

While each Strategic Initiative (SI) has a clear product and impact focus there are also strong interrelationships among the SIs (as shown in Figure 4), and they will be dynamically exploited. System-oriented SIs (SI 2 and SI 3) target farmers in different maize-based farming systems, and aim to develop scalable interventions that strongly reduce poverty among a large group of smallholders through cross-commodity, interdisciplinary approaches. Commodity-specific SIs (SI 4 to SI 7) generate technology and know-how that typically produce benefits regionally or across-continents. They however target distinct groups of clients—for example, institutions in low- and middle-income countries that request mycotoxin-resistant and drought-tolerant maize. The work of the commodity-specific SIs receives valuable input and priority setting from the systems-oriented SIs, into which their outputs also feed. The Global SIs (SI 1, SI 8, SI 9) provide context, and develop technologies and know-how that in many instances have global benefits. Such outputs are used in commodity-specific and system-oriented SIs and beyond, and also receive feedback from them.

While development of the various strategic initiatives was based on feedback from partners, they will be implemented in a dynamic way. First of all they provide a simple tool for partners to express priorities and needs based on region, strength of their own program, and farmers’ needs. Strategic Initiatives with large demand will be strengthened, and those with lesser demand de-emphasized. Partners that have similar interests can more easily be grouped within and across regions, their input better considered, existing donor projects integrated, common capacity-building needs identified, and impact pathways and role of partners more proactively developed. While largely implemented at the regional level aligned with regional priorities, they provide a simple vehicle for exploiting cross-regional synergies and learning.

Based on the maize systems described in Table 1 and current knowledge, potential target domains for particular combinations of SIs are shown in Figure 5. Proposed targets for other SIs are described in Section 2. Their implementation will be further adjusted on the bases of continuing and evolving feedback from partners and stakeholders, ex-ante and ex-post impact analysis in SI1 (socioeconomics and impact), and availability of funds. For example, many donors express strong regional preferences and these will need to be considered. Partners expressing the relative priorities and needs of various strategic initiatives by country and region will assist in making discrepancies between stakeholder needs, government and donor investments more visible.

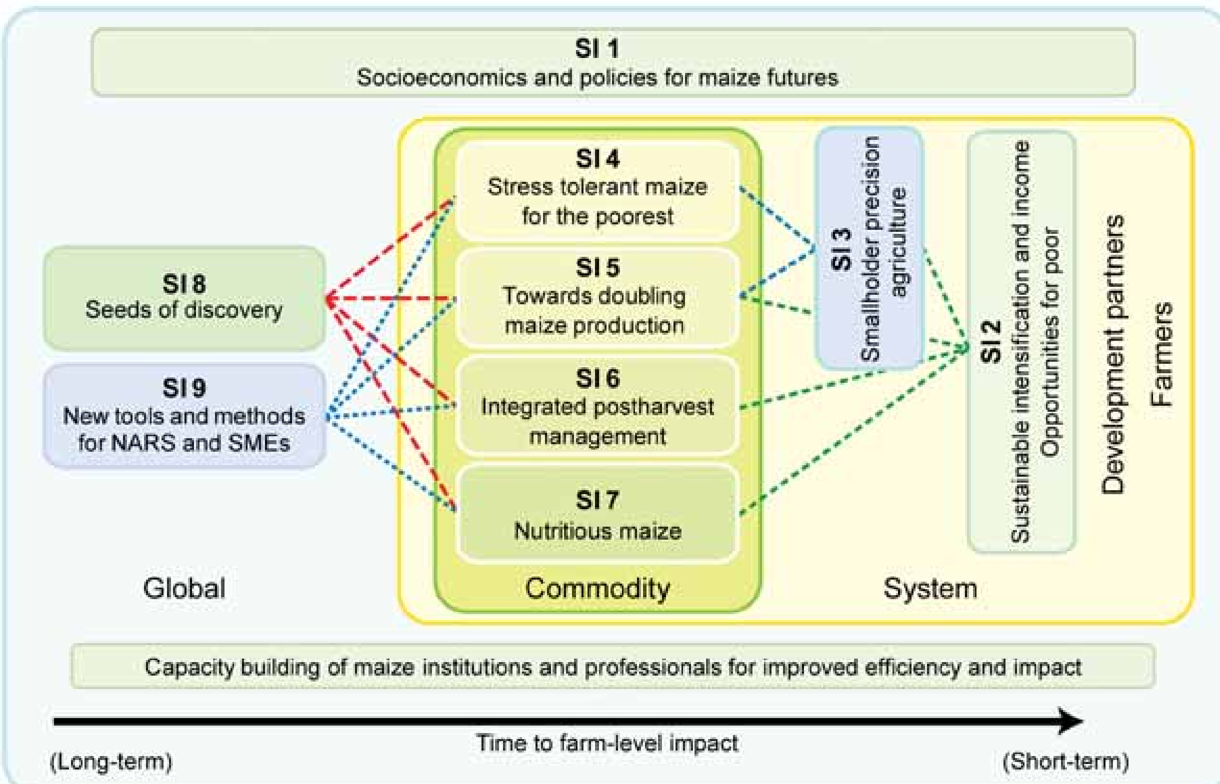

Figure 4. Output flows among MAIZE Strategic Initiatives.

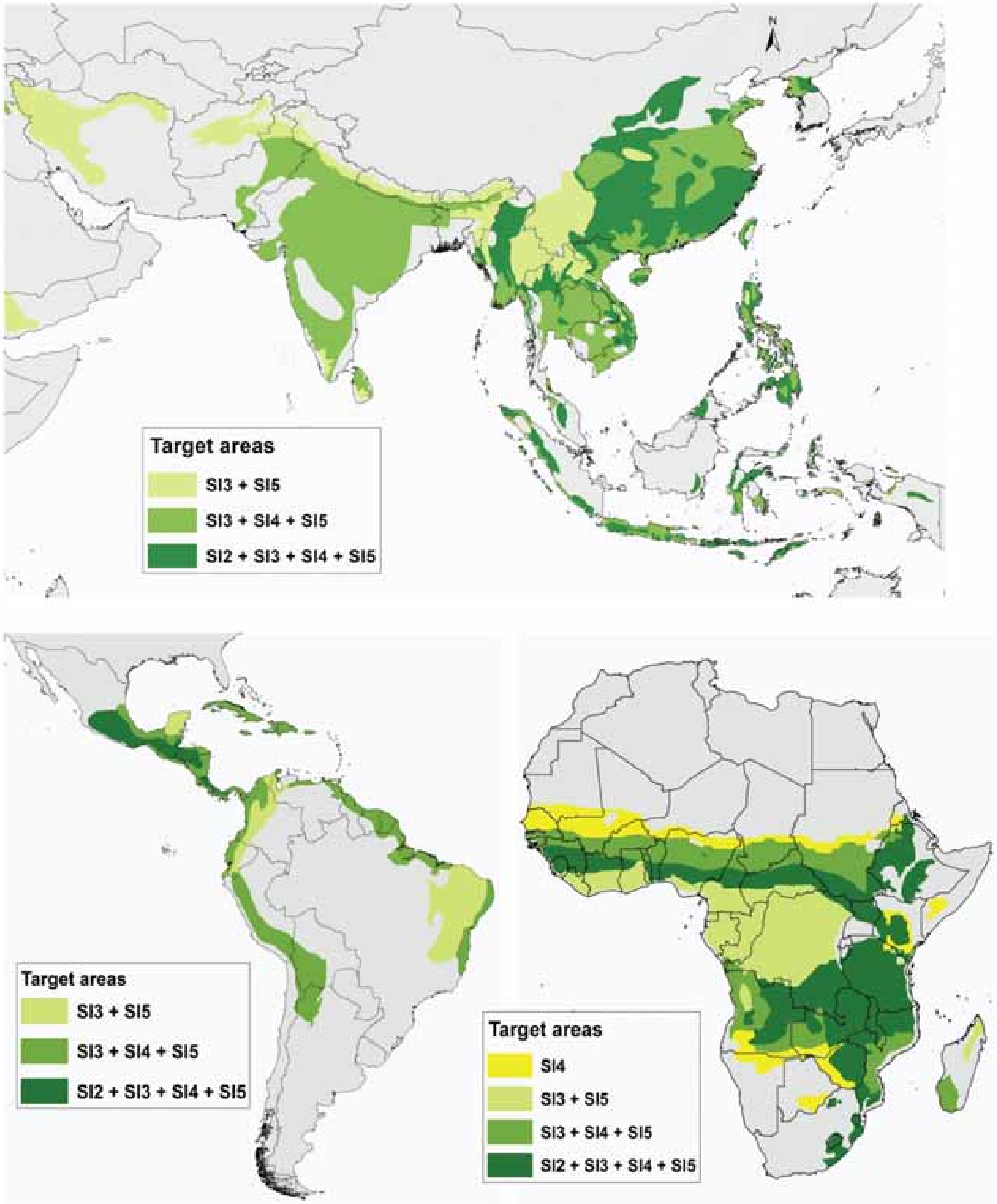

Figure 5. Target areas for Strategic Initiatives SI 2, SI 3, SI 4 and SI 5.

Program-level product delivery

Program-level product delivery, particularly the alignment of SI outputs with program-level outcomes, has geographic, socioeconomic, and temporal components.

1. Geography and socioeconomics. Developing countries maize farmers are predominantly smallholders who sow locally-adapted germplasm in settings that can vary greatly from location to location and often as part of an intercrop or rotation with diverse end uses. Access to input / output markets is highly variable, as are economic and policy environments. Figure 5 shows areas (dark green) where maize is a key crop and outputs from several SIs will prove relevant, based on current knowledge and partner consultations. Many SIs will have benefits far beyond these areas where systems-based MAIZE activities occur; the development of drought tolerant maize in SI4 in Africa, for example, will likely benefit these maize-systems based target areas in eastern and southern Africa *and* the northern Savannas, which are targeted only for attention under SI 4 (yellow). Indeed many germplasm related interventions or food-price related assessments, on the other hand, will have continent-scale or even global-scale impact.

As a result, outputs will be tailored to diverse settings and requirements and have different scales of geographic for impact; in fact, there will be a constant need to balance between scalable *versus* locally-targeted solutions and approaches. Ex-ante impact assessment and targeting in SI 1 and partner feedback will be very important to strike the appropriate balance in meeting client needs and maximizing impact.

In holistic, geographically-focused innovation and delivery systems, farmers participate, benefit, and gain awareness of and access to relevant technologies (seed, cropping practices, machinery implements, knowledge, etc.) through coordinated efforts among diverse value chain actors. MAIZE will catalyze the process as part of innovation networks or platforms centered around the six prioritized maize-based systems highlighted in Figure 5 in dark green, initially involving and supporting progressive farmers and value chain participants desirous of improvement and willing to innovate (Eckboir 2002). As the process matures, farmers and other value chain actors (NARS, private sector) drive innovation and help direct follow-up, backstopping research or other support.

To the same extent, at the global level Strategic Initiatives such as SI8 or SI9 imply various disciplines and partners engaging in joint learning as these initiatives progress. MAIZE will catalyze the process and naturally involve first the more progressive researchers and institutions that immediately see the merit and benefit of these initiatives. As work progresses, other researchers and institutions will understand the benefits, engage, and contribute to further innovation.

Changes over time. Aggregation of SI outputs will depend on the differential chronologies of their development and rollout. Interventions such as drought tolerant maize varieties available with the breeder today may take five and more years to pass through varietal testing and certification and have sufficient seed multiplied and availed. Information and communication technologies such as mobile phones and the internet for smallholder farmers, or conservation agriculture practices, will be ready for use much sooner. As a result, locally-focused innovation platforms in SI2 will facilitate farmer awareness and testing of diverse outputs as they become available, essentially drawing on MAIZE research outputs which individually have been generated in various years. This timescale is reflected as the X-axis in Figure 4.

What's new? - Overview of program innovations

Within the description of each Strategic Initiative we have highlighted the areas of greatest innovation. These fit together into the following exciting features of the entire CGIAR Research Program.

- A unified strategy for maize research in the CGIAR that offers a single point of investment for donors. The strategy builds on the strong and diverse partnership network of CIMMYT and IITA with public and private, upstream and downstream partners, and is expected to evolve including new partners.
- At the farm level, emphasis on cross-commodity, multi-institutional innovation systems, as opposed to the conventional linear model of information and knowledge flow within specific commodities.
- Through open-source breeding networks, transformation of international public maize breeding into a more demand-driven, consortium-based approach.
- Aggressive integration of the latest breeding science and tools to speed genetic gains.
- Access to transgenic variation, forthcoming mostly from multinationals, to develop products that will benefit the most disadvantaged countries and farmers.
- More efficient and flexible delivery to pre-commercial smallholder farmers in collaboration with NARSs, small- and medium-scale seed enterprises (SMEs), and farmer organizations.
- Emphasis on the need to develop human capacity, especially in NARESs and SMEs—to overcome prolonged underinvestment, ensure decentralized impact, make research-for-development more effective and enable exit strategies.
- A proactive gender strategy in all the Initiatives, focusing on empowering females and a future generation of professionals and farmers.
- Through the simplified product concept of Strategic Initiatives, enable a streamlined, rational partnership approach—with NARSs, SMEs, ARIs, universities, the multinational private sector, and emerging biotechnology capacities of institutes in developing countries—where priorities can be better captured and partners can optimize their engagement.

Impact pathways

Impact pathways are a method of making explicit our assumptions about the routes by which we expect Program actions to lead to desirable impact—in the case of the CGIAR, improvements in food, policy and environment oriented to the poor in developing countries. The most effective impact pathways are constructed and—because they are dynamic—regularly revised as an effort among research and development partners. They are product-specific and influenced by the presence and strength of various partners, which may differ and evolve to a different extent among countries even within the same region. Figure 6 can hence only present an overview of the highest level impact pathway that fits together our concept of how the nine Strategic Initiatives will respond to the needs of two principal target groups of MAIZE, while Annex 3 provides a more detailed presentation of the main outputs, outcomes, first- and second-order impacts, and enabling factors of the highest order impact pathway. During Program Implementation, the concept of Strategic Initiatives will facilitate the elaboration and utilization of Impact Pathways as a tool for more effectively targeting international agricultural research interventions, also for discussing the strategic involvement of research and development partners aligned with the particular presence and strength of partners in various regions, using tools such as Participatory Impact Pathway Analysis (PIPA; Douthwaite et al. 2003, 2009). Resulting impact pathways will be included in operational plans and annual reports.

The key MAIZE **outputs** include:

- Institutional and policy innovations and knowledge for improving targeting, markets, and value chains (SI 1 and SI 2).
- Crop and resource (soil, water, labor, income) management approaches, models and tools from SI 2 and SI 3.
- Improved germplasm (high-yielding, stress-resilient and nutritionally enriched inbreds, hybrids and OPVs) from SIs 4–7.
- Low-cost technological interventions and safe storage structures for effective post-harvest handling and storage of grain, reducing mycotoxin-related health risks and food contamination, from SI 6.
- Enabling tools and technologies resulting from SI 8 and SI 9 (novel genes, markers and alleles for the target traits resulting from SI 8 and SI 9; double haploids and molecular breeding and bioinformatics tools from SI 9).
- Capacity-building activities in each of the SIs will lead to a new generation of well-trained scientists (especially women and young adults) equipped to effectively implement the activities that will ensure MAIZE attains its strategic goals.

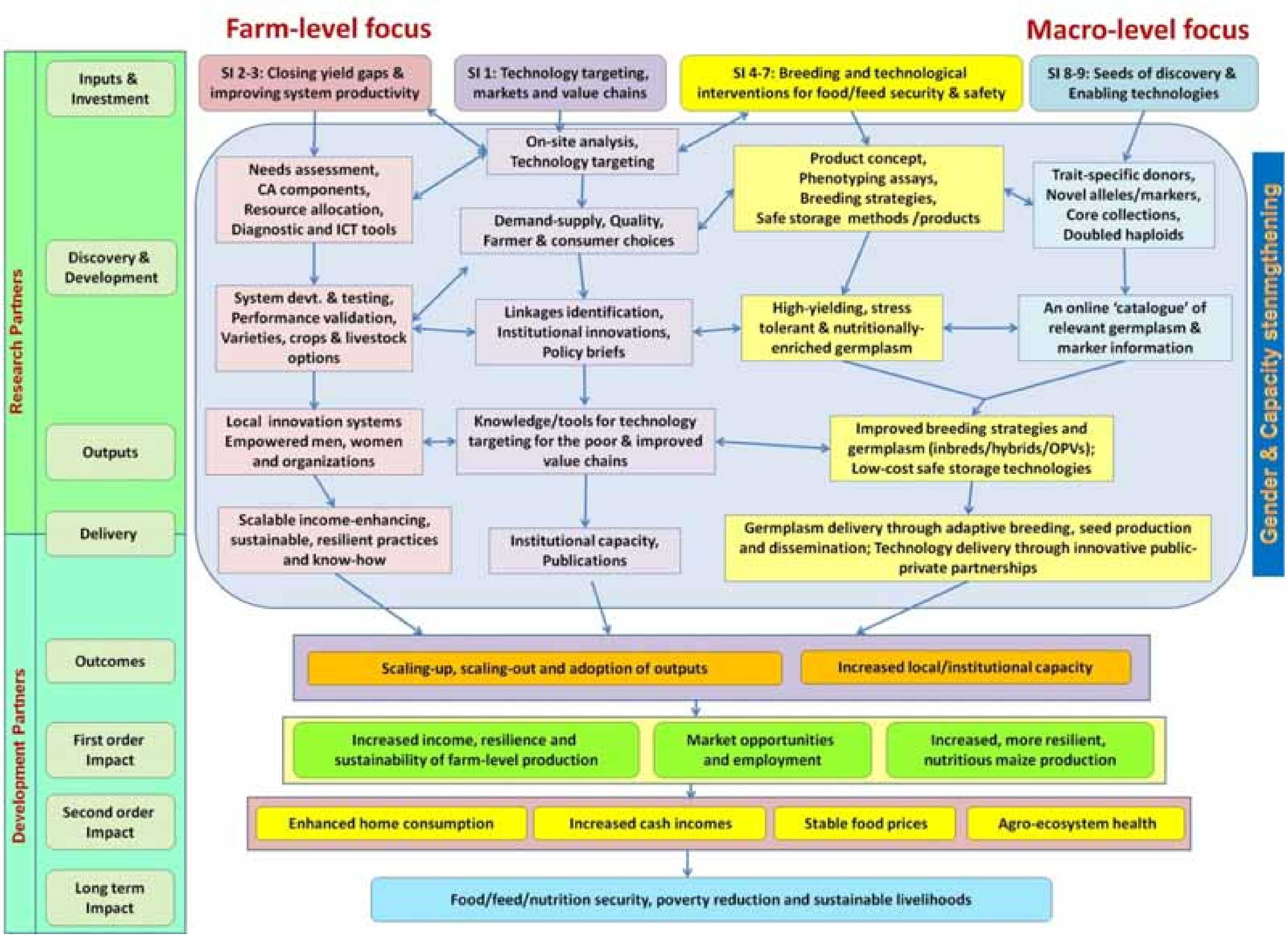

Figure 6. Schematic illustration of MAIZE impact pathway.

Outcomes for MAIZE as a whole shown in the Program Impact Pathway will include:

- The use and adaptation of research products by national partners to local conditions; the adoption of new tools, methods and institutional innovations by extension staff, NGOs and governments to better target the poor and deliver information to farmers.
- Use of innovative value chains by private sector and agro-dealers to develop the delivery of improved seeds, fertilizers and markets for maize farmers.
- Changes in know-how, capacity and attitudes by local partners in maize technology generation; targeting of subsistence farmers, especially women.

The key factors that determine **adoption** by farmers and diffusion of research products will include farmers' access to new information and awareness; expected benefits and local availability of new technologies; market access and opportunities (performance of input and output value chains); and access to credit and other policies to enable farmer investment in new technologies. Effective research-for- development partnerships and linkages in the impact pathway ensure that various local development partners will facilitate farmer access to information and innovations to stimulate adoption and scaling up of successful options.

Wider adoption of the outputs by the farmers will lead to **first order impacts,** which will include production/productivity increases, more resilient and nutritious maize production, sustainability of farm-level production, higher profitability of maize, and higher farmer income. Stronger maize value chains will lead to enhanced local capacity to manage production and market risks, market opportunities and employment. Focused gender and capacity building activities will lead to increased national capacity for technological and institutional innovations and accelerated translation of outputs to impact.

Second order impacts include enhanced food security of farmers, increased cash incomes of farmers, stable and lower food prices, increased non-food resources for consumers, and increased agro-ecosystem productivity and health. They will progressively lead to macro level economic, social and environmental impacts that contribute to sustainable intensification, poverty reduction and food security, even in the face of climate change and population growth.

The first and second order impacts are summarized diagrammatically in Figure 7. Data indicate that most MAIZE (and international agricultural) research outputs (technologies, know-how, policies, capacity building) impact farmers and consumers through work with government and non-government organizations, and also agribusiness—even though know-how may be scaled out to farmers directly through field days or new information and communication technologies.

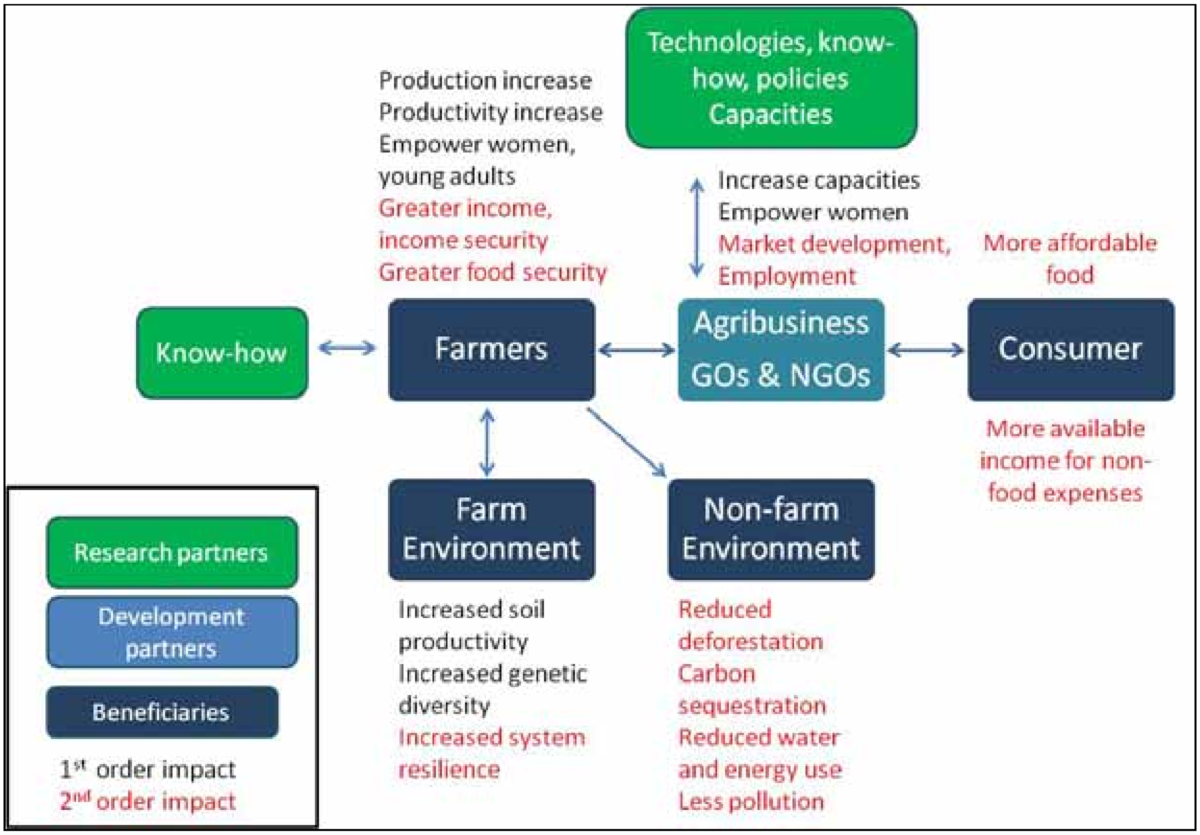

Figure 7. First and second order impacts aligned with location of impact.

Impacts

Estimated impacts of MAIZE on production, people, income, and food realized in 2020 and 2030 are summarized in Table 2; their link to the Strategic Results Framework of the CGIAR is outlined in Figure 8. The basis for the impact estimates are outlined in the various Strategic Initiatives in Part 2 of this document. Once fully deployed, and not accounting for the ongoing impacts of past research products, ***MAIZE is predicted to increase maize productivity in the two target groups by 7% by 2020 and 33% by 2030—adding an annual value of USD 2.0 billion by 2020, when it will reach 40 million smallholder farm family members, and USD 8.8 billion by 2030, when it is expected to reach 175 million family members. It is also expected to provide enough maize grain to meet the annual food demand of an additional 135 million consumers in 2020 and 600 million consumers in 2030***.

The portfolio of Strategic Initiatives will substantially increase the sustainability, resilience, and diversity of maize-based farming systems, reduce the need for maize area expansion, and also provide germplasm, tools and know-how to the new generation of women and men professionals who will help extend impacts. It will provide advice to policy makers on how better to respond to maize price-market fluctuations, with implications for more stable food prices. Broader impacts include:

- **Environment:** Increased land, fertilizer and water-use efficiencies; improved soil health; reduced soil erosion and flash flooding; reduced water pollution; increased carbon sequestration and reduced fuel use; increased deployment of maize genetic diversity; reduced need for farmers to expand maize area into forests and hill slopes; greater crop diversity.

- **Health:** Reduced health risks from mycotoxins and pesticide misuse; improved nutrition.

- **Equity:** More equitable access to knowledge, technologies, and opportunities for countries, institutions and disadvantaged groups(in particular women) in the developing world; reduced need for imports and food aid; greater dignity for people in drought-affected areas; reduced drudgery for women; increased schooling for children; strong and diverse participation in value chains and innovation by local companies.

- **Resilience:** Increased resilience from diversified income and reduced downside risk.

- **Leverage:** Catalytic effects on upstream research with downstream benefits in breeding programs including spillovers to non-maize R&D; stimulation of innovation in national research systems, local entrepreneurs, development partners and farmers; science-based information to policy and decision makers.

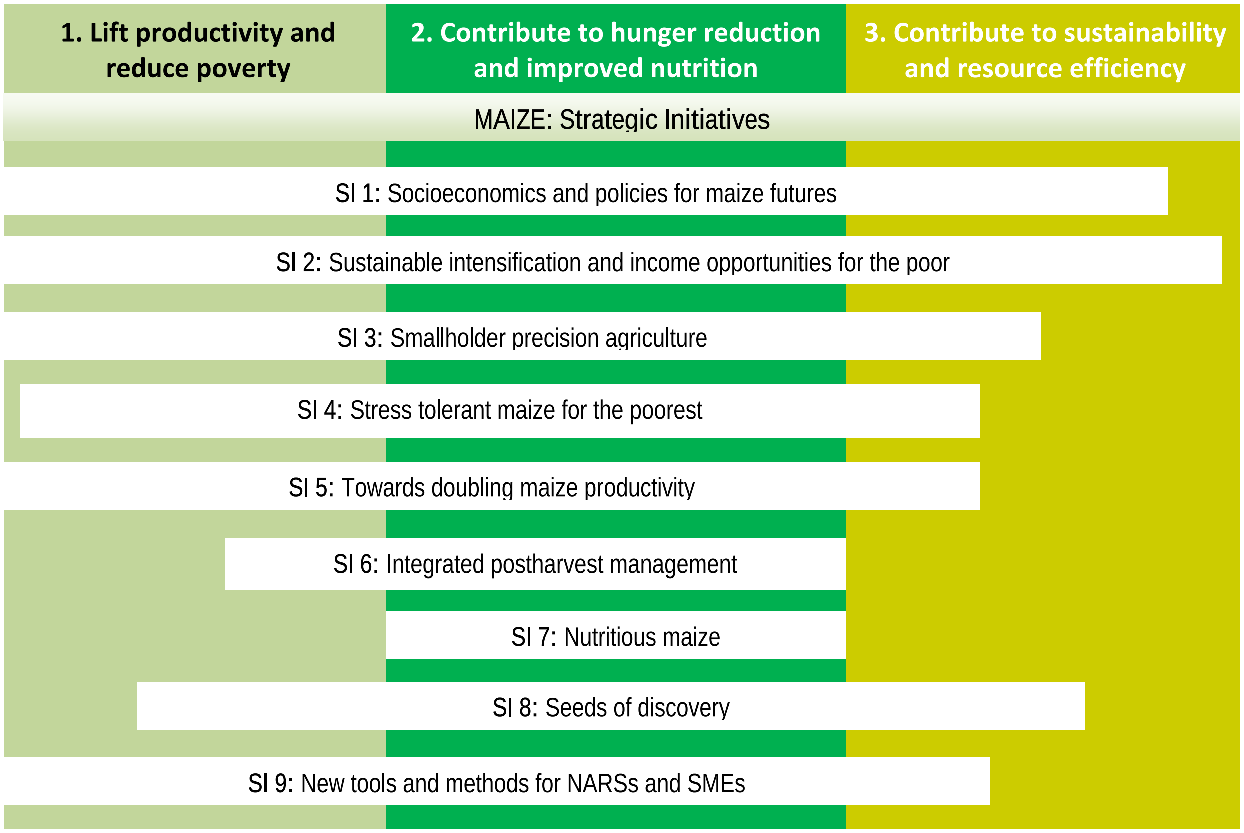

Figure 8. System Level Results Criteria. The bars for each Strategic Initiative show the extent to which it contributes to the three goals of the Strategic Results Framework of the CGIAR (CGIAR 2010).

Gender strategy

Male and female roles in agricultural production and household decision-making (resource allocation, technology adoption, marketing and consumption) vary across the target regions of Africa, Asia and Latin America. Gender relationships are embedded in complex social systems, generating status, power and decision-making roles that result in a gender-based division of labor, control and access to resources and incomes, preferences and needs. Consequently research interventions may differently affect the welfare and poverty conditions of men and women, and specific efforts are needed to address gender-specific issues and disparities between women and men.

Table 2. Summary of impacts of MAIZE on production, people, income and food.

Strategic Initiative	Production (mmt)		Production (USD)		Farmers		People		Income (USD)		30% of daily calories	
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
SI 1. Socioeconomics and policies for maize futures	Benefit contained in other strategic initiatives											
SI 2. Sustainable intensification and income opportunities for the poor	0.78	3.90	128	702	3.0	15.0	15.0	75.0	270	1,350	11	57
SI 3. Smallholder precision agriculture	1.20	9.60	197	1,728	2.5	20.0	12.5	100.0	237	1,788	18	141
SI 4. Stress tolerant maize for the poorest	1.70	4.50	418	1,215	6.0	18.0	30.0	90.0	418	1,215	25	66
Si 5. Towards doubling maize productivity	3.50	10.60	574	1,908	3.5	10.6	17.5	53.0	574	1,908	51	156
Si 6. Integrated postharvest management	1.20	3.60	197	648	2.0	6.0	10.0	30.0	197	648	18	53
SI 7. Nutritious maize	0.05	0.13	9	23	0.2	0.5	1.0	2.5	200	500	1	2
SI 8. Seeds of discovery	0.37	2.70	61	486					61	486	5	40
SI 9. New tools and methods for NARS and SMEs	0.40	5.50	66	990					66	990	6	81
Total Impact	**9.2**	**40.5**	**1,649**	**7,700**	**17**	**70**	**43**	**175**	**2,022**	**8,885**	**135**	**596**
Percent increase over current	7%	33%					6%	25%			10%	40%
Assumptions					Assumption: same farmers benefit twice							
Grain value (USD/mt)			164	180								
Family members (people per family)							5	5				
Food (kg maize to meet 30% of 2200 kcal diet)											68	68
SI1: Income addition p.c.								90		90		
SI3: Fertilizer value								40		60		
SI4: Reduction of variation			50%	50%								

While men are often regarded as household heads and the primary providers for families, women in many maize-based systems in Africa, Asia, and Latin America invariably contribute a major proportion of the labor in planting, weeding, harvesting, and processing as well as adopting the role of the primary caregiver for the family. Women often work longer hours than men and have much less access to land, credit, information, or extension advice, yet female-controlled income often correlates to better welfare outcomes within the household.

Women's access to key resources, including land, is commonly determined via their relationship to a husband or father. The fact that women play a major role in production in smallholdings but may not control the proceeds of their labor is detrimental to the wellbeing and food security of children and other dependants. Examples such as the proactive inclusion of women and disadvantaged groups in community-based maize seed production in Nepal or during participatory variety selection in Ethiopia and Mexico show that research can influence established community patterns for greater research-for-development outcomes (Hellin et al., 2010; La Rovere et al., 2008 and 2009; Mathema and Gurung, 2006).

With an increasingly aging farming and agricultural research community, partners also strongly raise their voice for more proactive engagement of younger professionals and farmers as they will to a great extent determine the effectiveness and adoption of research-for-development interventions.

MAIZE will take specific steps to understand gender-based dynamics and differences, and leverage this knowledge so that interventions will address gender-specific needs, promote options that create opportunities and empower women and young adults; and foster strategies that change prevalent attitudes and mindsets to enable equitable and inclusive growth. Building upon current activities, this will be done through five main approaches:

- Socioeconomics research under SI 1 will systematically assess and identify gender-differentiated technology needs, choices, impacts, and constraints to inform the design and targeting of new technologies. SI 1 will also test mechanisms that enhance technology targeting, delivery and equitable access for both men and women, and assess the impact of MAIZE interventions on the welfare of men and women as well as on child nutrition and school enrollment. The researchers will use the results to strengthen in all the other Initiatives the development of MAIZE technologies and innovations that better meet the needs of women, reduce gender disparities, and engage women more strongly in collaborative research and capacity building.

- Farmer participatory research in system-oriented and commodity-specific MAIZE SIs will actively promote the participation of women and young adults in innovation systems, technology testing, and development—to both empower and ensure that their input is being included in on-going research. Female focus groups will be engaged to better understand gender roles and define how MAIZE-specific interventions may be used to expand livelihood opportunities for women and children's education. As women shoulder the bulk of domestic responsibilities and are unable to allocate their time to more productive (or remunerative) activities unless their labor productivity increases, introducing technologies in SI 2 (smallholder intensification and income opportunities) that reduce women's time and energy expenditures can enable women to invest in income-generating activities, childcare and education, as well as allowing girls to attend school. The technology development efforts for specific maize varieties under commodity-specific SIs 4 to 7 will take into account the value of maize as a source of food security, nutrition and income, along with trait preferences (storage and processing quality, cooking quality, taste, aroma, and color, among others) of both men and women. Women farmers will be mobilized to participate in demand studies and variety selection trials and demonstrations, and to explore tradeoffs between home consumption preferences, technology adoption, and meeting the growing market demand for maize (mainly for feed).

- Across Strategic Initiatives, women and young adults will be given preferential access to capacity-building efforts, whether as researchers, entrepreneurs or farmers.

- Key performance indicators will be updated regularly to monitor progress on gender issues as part of monitoring and evaluation.

- During the first two years of implementation MAIZE will also execute an external gender audit across all nine strategic initiatives, to examine to what extent and beyond current practices these initiatives could better address gender-specific needs, promote options that create opportunities and empower women and young adults, and also foster strategies that change prevalent attitudes and mindsets to enable equitable and inclusive growth. The results of the gender audit will provide practical steps and advice for MAIZE researchers to be more effective in implementing gender-sensitive research-for-development approaches, and lead to improved approaches for monitoring and evaluating the effectiveness of the gender strategy.

Partnership strategy

The network of partners

A large network of partners will implement MAIZE. They will capture a wide range of innovative ideas, ensure the quality of the research, and integrate the skills of the most able and well-connected members. Many of these partnerships already exist, having evolved during collaborative planning of priority activities in past years. They have strongly influenced MAIZE as presented in this document, are the basis for current research teams and alliances, and provide the rationale for the strong regional focus and "bottom-up" (national => regional => global) approaches to priority setting, collaboration, and decision making, as depicted in Figures 9 and 10.

Partners indicated their priorities for international research interventions—these were formalized as MAIZE Strategic Initiatives—and their desired involvement in international maize research (summarized in Table 3). Forms of partner engagement are also described in detail in Section 2 of this document. The extent of partner engagement will depend significantly on available funding, both through MAIZE or other sources (for example, national budget allocations to national agricultural research systems).

The Strategic Initiatives are diverse and each involves a different network of partners. Global initiatives such as SI 8 (Seeds of Discovery) and SI 9 (New tools and methods for national research systems and small- and medium-scale enterprises) focus strongly on research and information-management partners; systems-focused initiatives such as SI 2 (Sustainable intensification and income opportunities for the poor) and SI 3 (Smallholder precision agriculture) need a wide range of national, regional, and international partners for both research and development. SI 5 (Towards doubling maize productivity) and to some extent SI 4 (Stress-tolerant maize for the poorest) gain strength from the innovative interaction of public and private partners, with MAIZE as a neutral facilitator of effective partner interactions.

In the current program formulation, some 343 partners are included (for a complete listing, see Annex 2). For 179 of these, research involvement is documented through formal agreements and includes access to joint research funds. Of the 343 partners, 130 (70 funded and with formal agreement) are national agricultural research systems, 75 (38 funded and with formal agreement) are universities in developing countries, 18 (6 funded and with formal agreement) are regional and international organizations, 21 (4 funded and with formal agreement) are advanced research institutes (ARIs), 46 (22 funded and with formal agreement) are from the private sector, and 42 (4 funded and with formal agreement) are non-government organizations (NGOs), community-based organizations (CBOs) and farmer cooperatives.

Partner engagement is primarily by consensus, following collaborative planning or based on peer-review (see below). However, the high level of bilateral funding in MAIZE means that donors strongly influence the choice of financially-supported partners, mostly by determining the geographic focus (investments in sub-Saharan Africa are emphasized over investments in Asia, Latin America, or for global activities) and type of investment (about 60% of the resources to partners are allocated for local adaptive research and high-leverage deployment activities that foster impact). In many instances, donors take a strong role in co-conceiving bilateral projects and have very specific ideas regarding whose participation to fund.

Whereas CGIAR unrestricted funding to MAIZE will make up the difference between bilateral funding and desirable investments by Strategic Initiative and region (prioritization for this will be influenced by partners, as described in the Budget section), the amount of available funding may limit the extent of partner engagement. For example, maize-based systems research in SI 2—an initiative that requires strong partner engagement—was prioritized for six internationally relevant maize based systems with high poverty rates (Figure 3, Annex 1). Currently only three of those systems, accounting for 200 million maize-dependent poor, have attracted bilateral donor support. CGIAR or additional bilateral resources fall short of making up the difference to engage partners for the other three systems (which account for 224 million maize-dependent poor).

MAIZE has a very high commitment to regionally-prioritized approaches and involving NARS in the target regions in the research-for-development agenda. In 2010, financially-supported partners to CIMMYT and IITA coordinated research (ie the equivalent to "MAIZE") included the following:

- **Partners for globally-managed activities (8% of all partner funding):** Yunnan Academy of Agricultural Sciences in China, Kenya Agricultural Research Institute in Kenya, Syngenta Company, the University of Freiburg and the University of Hohenheim in Germany, and Virginia Tech University in the USA.
- **Regional or international partners for regionally-managed activities (31% of all partner funding):** Africa Agricultural Technology Foundation in Kenya, the Association for Strengthening Agricultural Research in Eastern and Central Africa, ICRISAT, IFPRI, K BioSciences, Monsanto, Murdoch University in Australia, Pioneer HiBred, Queensland Department of Employment, Economic Development and Innovation, Queensland University in Australia, and the University of Georgia.
- **National partners for regionally-managed activities (61% of all partner funding):** Members of NARS-led national maize working groups—including NARS, the private sector and CBOs/NGOs—in Angola, Bangladesh, Benin, Botswana, El Salvador, Ethiopia, Ghana, Honduras, India, Kenya, Lesotho, Malawi, Mali, Mexico, Mozambique, Nepal, Nicaragua, Nigeria, Peru, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. Funding allocations are decided after peer review; subcontracts are based on prioritization and advice from regional steering committees.

It should be noted that funding flows from internationally-funded maize research activities give an inappropriate impression of the extent of MAIZE partnership support. Much of the impact and leverage of international maize research investments result through partnering with self-funded partners world-wide (listed in Annex 2). These partners may benefit from CGIAR funded information exchange, planning workshops and training events, yet they invest significant amounts of their own resources when they take part in collaborative activities. One example is maize germplasm development and dissemination activities (SI 4 and SI 5) in South and Southeast Asia; these are spearheaded and significantly supported by national agricultural research systems, universities, and the local private seed sector in Bangladesh, China, India, Indonesia, Nepal, the Philippines and Vietnam, in interaction with CIMMYT offices in India, Nepal, and Mexico, the international collaborator network of the Generation Challenge Program, and Syngenta Company.

Another version of self-funding and an important form of collaboration originates from projects aligned with MAIZE but managed by non-CGIAR organizations or other CRPs. One example is the Water Efficient Maize for Africa (WEMA) project, which is managed by the Africa Agricultural Technology Foundation (AATF) in Kenya and executed in collaboration with Monsanto, CIMMYT, and research programs and regulatory agencies in Kenya, Malawi, Mozambique, Tanzania, and Uganda. Valuable collaborative activities for MAIZE have also recently emerged from "BREAD"-funded projects, originating from the

National Science Foundation in the USA and supporting important MAIZE-relevant partnerships with US universities, USDA, and national agricultural research systems of diverse countries.

Among the CGIAR centers listed on the title page, ICRISAT and IFPRI currently receive research funding from MAIZE equivalent activities. There are a number of collaborative activities which are not documented through funding flows, and funding could evolve for the other centers (CIAT, ICRAF, ILRI, and IRRI) to be included in forthcoming MAIZE-funded activities. As an example, advanced discussions are now under way to fund ILRI in SI2-related maize-legume systems activities in eastern and southern Africa.

Partnership interactions

Based on this strong and dynamic partnership network, MAIZE partnership approaches will initially be structured around four sub-regions—West and Central Africa, eastern and southern Africa, Asia and North Africa, and Latin America and the Caribbean, for SI 1 through SI 7 (Figures 9 and 10). Global strategic research is associated with SI 8 and SI 9. As MAIZE activities progress, collaborators will prioritize and redefine their engagements through systematic web-based interactions and annual meetings, thereby streamlining and focusing both funded and self-funded partnership engagements, increasing cross-regional collaboration, and formalizing the engagement of new partners, as well as capitalizing on experiences in different geographic regions (crucial for activities in systems-focused Strategic Initiatives).

Given the high level of bilateral funding for MAIZE, the short duration of bilateral projects (average: 2 years), the role of external and MAIZE-managed funding, and other reasons (staff and leadership changes in partner organizations, changes in national and institutional priorities), partnerships in MAIZE will be fluid. Partners will join or leave, modify their roles, and participate less or more in priority-setting and decision-making according to their own preferences and to the way other partners perceive their present and potential contributions.

Annual **research planning and review meetings** in the four sub-regions and for the global Strategic Initiatives will constitute fundamental tools to manage and allocate funds for partner engagement, and do so in a participatory manner. Research planning and review meetings will focus on relevant Strategic Initiatives by sub-region, include research partners in a meeting agenda that is differentiated by the extent of on-going activities in a particular sub-region, and include both MAIZE-wide and SI-specific discussions. One effective tool to agree upon future activities and research partners is participatory priority setting, based on impact pathways, available budgets, peer-review, track record of fulfilling past commitments, and existing or likely contributions of research and development partners.

Priority setting to plan future revisions of MAIZE will require the widespread involvement of stakeholders and emerge from Web-based surveys, the result of the impact and targeting work conducted as part of SI 1, external studies, interactions with sub-regional organizations, governments of individual countries, and distinct stakeholder groups such as the private companies or farmer associations. The compiled feedback will form the basis for physical stakeholder meetings in Year 3. The outcome of the stakeholder meetings will form the basis for the MAIZE proposal that is submitted to the Consortium Board for the next performance contract.

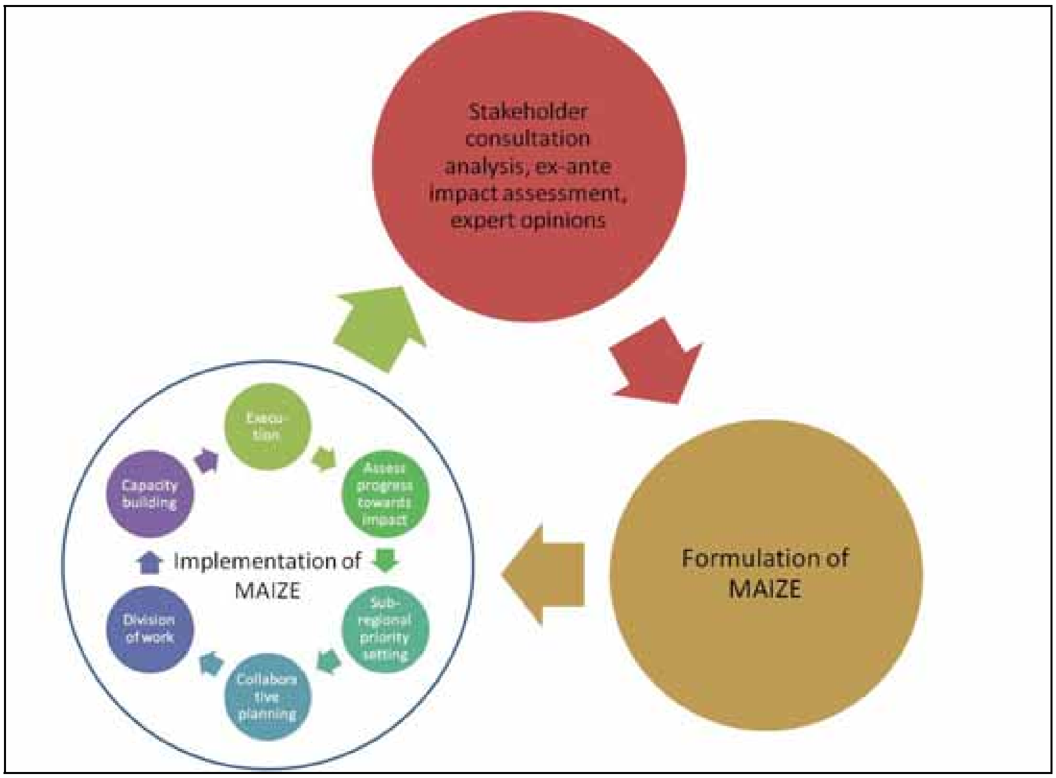

Figure 9. Collaborative planning and implementation of MAIZE.

Table 3. Tentative engagement of partners in collaborative implementation of MAIZE Strategic Initiatives.

Strategic Initiative	Partner type	Partner roles
Across MAIZE	Top universities in Africa, Asia and Latin America	Co-supervision of PhD students for "sandwich programs" Have or adopt MAIZE research topics as a major research theme Select and source or provide stipends for top students
SI 1. Socio-economics and policies for maize futures	NARESs in Africa, Asia and Latin America	Socio-economic, value chain and gender analysis and targeting, and development of institutional innovations within-country but for regionally relevant/prioritized systems
	CIMMYT and IITA	MAIZE-specific coordination, facilitation and state-of-the-art socio-economic, value chain and gender analysis and targeting, and development of institutional innovations at the regional and international level; capitalize on interdisciplinary linkages and know-how of technical and social scientists
	IFPRI and universities	Cross-sectoral, cross-commodity knowledge, tools, methods and experiences for socio-economic and value chain analysis and targeting, institutional innovations and drivers of change; linkages to policy networks
	Universities (e.g. Cornell, Gottingen, Michigan State, Stanford, UMB-Norway) and top universities in Africa, Asia and Latin America	Co-supervision of PhD students for "sandwich programs" Have or assume selected priority research topics in SI 1 as a major research theme
	Regional and global policy research institutes, networks and commissions (e.g. FANRPAN, COMESA), sub-regional organizations and Ministries of Agriculture and Finance	Linkages to policy implementation; important clients of outputs of SI 1
	MAIZE collaborators engaged in other Strategic Initiatives; decision makers in MAIZE and the CGIAR	Important clients of outputs of SI 1

Strategic Initiative	Partner type	Partner roles
SI 2. Sustainable intensification and income opportunities for the poor	NARESs in Africa, Asia and Latin America	Farming system and value chain analysis, farmer participatory research (conservation agriculture, varieties, commodity mix) within-country but for regionally relevant/prioritized maize-based systems, using the concept of innovation platforms/hubs; main hub/innovation platform managers
	CIMMYT and IITA	Facilitation of innovation systems approaches for most important maize-based systems (i.e. where maize is the dominant crop), cross-national, cross-regional and cross-program learning and knowledge management; maize-specific inputs from other Strategic Initiatives such as germplasm, conservation agriculture approaches, nutrient management approaches, maize-relevant GIS information, impact and targeting information
	Universities (Cornell, Stanford, Oklahoma State, Florida, Washington, UMB-Norway, APSRU-Australia); other ARIs (CSIRO, CIRAD, EMBRAPA)	Members of inter-institutional research for development (R for D) team to identify promising technology for conservation agriculture, crop rotation, crops, trees and livestock, and conduct applied research on-farm
	CIAT, CIP, ICRISAT, IITA, ICRAF, ILRI, IRRI, Universities (Cornell, Stanford, Oklahoma State, Florida, Washington, UMB-Norway, APSRU-Australia); other ARIs (CSIRO, CIRAD, EMBRAPA)	Members of inter-institutional R for D team providing specific technologies and know-how on conservation agriculture, crop rotation, crops, trees and livestock, systems modeling, use of ICT and scaling out
	Farmers, input and output market participants including: equipment manufacturers, seed companies, agro-dealers, farmer cooperatives, grain merchants, credit agencies, regulatory agencies, seed trade associations, etc.	Members of the innovation research network, providing feedback, executing part of the research (e.g. on-farm research, farmer-led research, new machinery, seed production for farmer-participatory research trials) and use, adapt and scale-out successful research outputs
	Local and international NGOs and CBOs, extension providers, NARSs, seed companies and networks (e.g. the African Conservation Tillage Network), farmer organizations, regional and international organizations (e.g. FAO, AGRA)	Feedback to and scaling out of SI 2 know-how and information; adoption of innovation platform/hub concept for local adaptive systems innovation, depending on their geographical presence
	Private sector ICT companies	Collaborator in designing, testing and implementing the dissemination of scalable, GIS- and MIS-responsive information to farmers and extension

Strategic Initiative	Partner type	Partner roles
SI 3. Smallholder precision agriculture	At least five IARCs (CIMMYT, CIAT, ICRISAT, IITA and IRRI); Universities (Cornell, Stanford, Oklahoma State, North Carolina, Adelaide); other ARIs (International Plant Nutrition Institute, ICAR-India, CAAS-China and EMBRAPA)	Specialist knowledge in precision agriculture applied to field situations
	CIMMYT and IITA	Facilitation of the international exploratory diagnostic trials, development of international database, ensuring appropriate data processing to enable precision agriculture applications pioneered by research partners
	NARESs where the target farming systems are important, including universities; the private sector (i.e. seed companies and farm implement manufacturers); NGOs and farmer groups.	International exploratory diagnostic trials; experimentation with pioneering precision agriculture implementation
	Private sector ICT companies	Collaborator in designing, testing and implementing the dissemination of scalable, GIS- and MIS-responsive information to farmers and extension providers
	Local and international NGOs and CBOs, extension providers, NARSs, seed companies and networks (e.g. the African Conservation Tillage Network), farmer organizations, regional and international organizations (e.g. FAO, AGRA)	Feedback to and scaling out of SI 3 know-how and information; adoption of research concepts for generation of more localized information, depending on their geographical presence
SI 4. Stress tolerant maize for the poorest	NARSs and local seed companies in sub-Saharan Africa and Asia and in poverty pockets in Central America	High-quality collaborative phenotyping, open-source breeding and testing for stress-prone environments, clustered by mega-environments, agreed trait priorities and client needs; managed through competitive performance contracts
	CIMMYT and IITA	Facilitation and participation in collaborative germplasm development with particular focus on cutting-edge breeding approaches (doubled-haploids, genomics selection, precision phenotyping) for stress environments; international data exchange and main source germplasm provider; seed business training and value chain analysis for stress environments; broker for use of proprietary know-how, technologies and germplasm

Strategic Initiative	**Partner type**	**Partner roles**
SI 4. Stress tolerant maize for the poorest	Multinational seed companies and biotechnology organizations (building on successful collaboration with Monsanto, Syngenta, AATF and Pioneer); ARIs (e.g. Cornell University, Hohenheim University) including those in the developing world (Brazil, China, India, Mexico)	Positional cloning of relevant native-trait alleles and transgene sourcing and deployment; transgenic trait research; new breeding methods
	NARSs, local seed companies, NGOs and CBOs in drought-affected countries in Africa, Asia, and Latin America.	Local variety adaptation/selection, release, and scaling-out to farmers in stress-prone environments
	Development partners engaged with farming families and communities	Improve technical services and market access
SI 5. Towards doubling maize productivity	Economists in NARSs, IARCs and universities	Rapid, participatory assessment of maize germplasm needs of pre-commercial farmers, distinguished by gender, poverty group, mega-environment and market access
	NARSs and private sector in Africa, Latin America, and Asia that are able and willing to engage in open-source breeding, can provide rapid return of high-quality data, and have effective germplasm import/export approaches	High-quality collaborative phenotyping, open-source breeding and testing targeted at pre-commercial farmers, clustered by mega-environments, agreed trait priorities and client needs; managed through competitive performance contracts
	CIMMYT and IITA	Facilitation and participation in collaborative germplasm development with particular focus on cutting-edge breeding approaches (doubled-haploids, genomics selection, precision phenotyping) targeted at the needs of pre-commercial farmers; international data exchange and main source germplasm provider; broker for use of proprietary know-how, technologies and germplasm
	Formalized members of International Maize Improvement Consortium (IMIC) from NARSs, private sector and NGOs.	Set development priorities that influence breeding; comply with obligations to report on germplasm performance and use (in return, get rapid and preferential access to germplasm, training, and crop management innovations); non-members to get access to a more limited germplasm as IPGs

Strategic Initiative	Partner type	Partner roles
SI 6. Integrated post-harvest management	IARCs (CIMMYT, IITA, ICRISAT, IFPRI); Universities (Texas A&M, Tecnológico de Monterrey); other ARIs (Max Planck Institute for Molecular Plant Physiology, USDA-ARS, CINVESTAV-Mexico); NARSs (e.g. Central and South American NARSs engaged in PostCosecha)	Specialist knowledge in postharvest pest control, mycotoxins, low-cost grain storage
	NARESs and NGOs; regulatory authorities	Testing and adaptation of priority innovations at local level
	CIMMYT and IITA	Scaling up and out of successful concepts, cross-regional and cross-institutional learning and knowledge management; establishing and testing crop loss and contamination risk models for GIS-based targeting of efforts
	NARESs; grain dealers; NGOs, CBOs and farmer organizations; World Food Program, WHO, FAO; KEMRI/CDC (Kenya), NAFDAC (Nigeria) and the Millennium Village Project (Nigeria)	Scale-out innovations at local, regional and international level
SI 7. Nutritious maize	NARESs (INTA-Nicaragua, CENTA-El Salvador, DICTA- and UNAM-Honduras, ICTA-Guatemala, ORE-Haiti, ICAR-India, MoA-Indonesia; NARC-Nepal; BARI-Bangladesh, ZARI-Zambia, IAR- and NAERLS-Nigeria, INERA-Burkina Faso, FAES-Senegal, EIAR-Ethiopia, IKIRU and IIAM-Mozambique, CRI-Ghana, INRAB-Benin, IER-Mali); private seed companies (ZamSeed, SeedCo, Premier Seeds Nigeria Ltd, Alheri Seeds Ltd, Syngenta, Bioseed of India, Ceres, Aspros); regional organizations in Africa (FARA, ASARECA, CORAF)	Development and evaluation of locally adapted, nutritionally enriched, agronomically superior varieties and hybrids
	CIMMYT and IITA	Development of nutritionally enhanced germplasm based on clearly indentified needs and demands, for local adaption and use by NARSs and local seed companies; development of protocols and quality assurance for new types of grain quality analysis
	HarvestPlus members; CIMMYT, IITA, University of Wisconsin, Purdue University, Cornell University, ILRI, CIP	Human nutrition, food technology, nutrient analysis, feed/forage analysis, micronutrient research, and other complementary topics

Strategic Initiative	Partner type	Partner roles
SI 7. Nutritious maize	In Zambia, MoA (including research and extension divisions), Ministry of Health, NGOs (Care International, Program Against Malnutrition, World Vision) and NARS (NISIR).	Adaptation and dissemination of pro-vitamin A-enriched maize germplasm in Zambia
	NGOs (e.g. Sasakawa Global 2000, World Vision International, Catholic Relief Services, World Food Program) and private sector	Contract- or market-driven dissemination of QPM germplasm.
SI 8. Seeds of discovery	Maize phenotyping network members from NARSs, ARIs, universities, and the private sector	Phenotyping of diverse genetic resources for priority traits; managed through competitive performance contracts
	Sequencing/genotyping experts at Cornell University, Beijing Genomics Institute and CINVESTAV	Sequence entire native maize genetic variation using next generation genotyping-be-sequencing approaches
	IP Managers from CIMMYT, IITA and other germplasm bank holders (e.g. Mexico), IP experts at the Global Crop Diversity Trust, FAO, Bioversity, PIPRA, CAMBIA (Patent Lens), and from the public and private sector	IP framework, guidelines and agreement for equitable use of the Seeds of Discovery platform aligned with the International Treaty on Plant Genetic Resources on Food and Agriculture
	IT experts and software developers at SCRI, Cornell University, CIMMYT, the GIBS, genebanks and universities; the Maize and Sorghum USDA AFRI CAP project; maize and IP on-line resources at Iowa State University (MaizeGDB), NCBI (GenBank).	Analyze and manage sequencing and phenotyping data for web-based access of Seeds of Discovery data, linked to other germplasm resource systems
	CIMMYT and INIFAP-Mexico	Germplasm increases and curation
	Breeders at CIMMYT, IITA, national research programs, advanced research institutes, universities, and seed companies;	Mobilize novel alleles into breeding programs via seeds or introgression lines in support of accelerating breeding progress and ex situ
	Plant scientists worldwide using the Seeds of Discovery platform, seeds or introgression lines for research.	Develop novel knowledge about maize genetic variation and its relevance for accelerating breeding progress, stress tolerance and resistance, nutrient use, the deployment of genetic diversity, and ecosystem resilience
	Patent offices	Evaluate prior art during the patenting process

Strategic Initiative	Partner type	Partner roles
SI 9. New tools and methods for NARSs and SMEs	Leading ARIs, selected NARSs and seed companies.	Refine new breeding tools
	CIMMYT and the University of Hohenheim.	Development of publicly available doubled haploid tropical inducer and system
	Beijing Genomics Institute	Sequencing of AM panel resources
	CIMMYT, IITA, drawing on knowledge from ARIs (e.g. Cornell and Hohenheim University) and the multinational private sector	Develop and implement genomic selection, high-density genotyping, and high-throughput DNA extraction protocols, tuned to the needs and capacities of NARSs and local seed companies
	NARSs and SMEs with applied maize breeding programs	Use tools and methods in breeding programs and seed production
	NARS maize programs; FAO, ARIs, private sector; trade associations; NGOs, INGOs and CBOs	Development-oriented scaling-up of capacity building outputs

Partnership principles

While the partners themselves during program implementation will evaluate the quality of partnership interactions, partnership principles will be guided and revised by experiences from MAIZE implementers, the CGIAR and beyond (based on Woolley et al. 2009). They include:

- Involve the right people and organizations.
- Agree on guidelines about how responsibilities are assigned and conflict resolution processes.
- Within the overall impact targets, agree on clear and mutually agreed milestones and make impact pathways explicit.
- Share recognition and responsibility for outcomes.
- Allocate time and resources for effective development of partnerships, including the development of trust and a common language.
- Give leadership responsibilities to non-CGIAR partners.
- Clarify expectations about time investment in decision-making, meetings and program execution.
- Keep decision-making and communication transparent.
- Focus on simple and efficient processes.
- Value performance above "politics, seniority, or hierarchy".

The Program has developed initial guidelines **of important attributes for high-quality research and development partners;** the guidelines will be used in partner selection and reviewed from time to time.

Attributes of a research partner (all of the following):

- Commitment to the values, outputs, outcomes, and impacts of MAIZE.
- Recognized authority in required technical area(s) that are complementary to the strengths of existing partners.
- Willing to generate and exchange high-quality information, knowledge, germplasm, tools and/or methods to produce international public goods and to adhere to the core MAIZE principles of intellectual property management.
- Willing to commit financial and human resources to agreed priority research activities.
- Demonstrated efficiency and probity in use of funds (if the partner is to receive budget from MAIZE).
- Willing to share field and laboratory facilities.

Attributes of a development partner (the first two, and at least one of the other criteria)

- Commitment to the values, outputs, outcomes, and impacts of MAIZE.
- Demonstrated efficiency and probity in use of funds (if the partner is to receive budget from MAIZE).
- Track-record in improving the livelihoods of smallholders in relevant farming systems.
- Capacity to positively influence national, regional or international policies and institutional innovations in agriculture.
- Commitment and expertise in promoting local institutional capacity and gender mainstreaming.
- Flexible capacity to handle dynamic scaling-up and scaling-out of knowledge.

Oversight and management

Organization of MAIZE

MAIZE uses a simple, cost-effective design for oversight and management that is based on the management principles defined in the Strategic Research Framework and the standard performance contract of the CGIAR Consortium. It uses current institutional capacities and networks, and largely focuses on the pragmatic implementation of a research agenda that involves a very large number of partners and is driven by stakeholder priorities and inter-institutional teams, as described in the last section and visualized in Figure 10.

Except for the global initiatives SI 8 (Seeds of discovery) and SI 9 (New tools and methods for NARSs and SMEs), MAIZE will be implemented in a decentralized manner to ensure participatory decision making, effective engagement with regional and local partners, local capacity strengthening and focused regional impact. The primary axis of implementation is therefore in four regions: West & Central Africa; Eastern & Southern Africa; Asia & North Africa; Latin America & the Caribbean; implementation will follow the partnership approaches outlined in the previous section that emphasize:

- Regional priority-setting among and within various Strategic Initiatives.
- Collaborative planning, execution and assessment towards impact.
- Needs-driven capacity building.

It is important to understand just how strong this decentralized participatory structure is: Currently over 90% of partner funds are managed through participatory approaches at the regional level and only 10% at the global level.

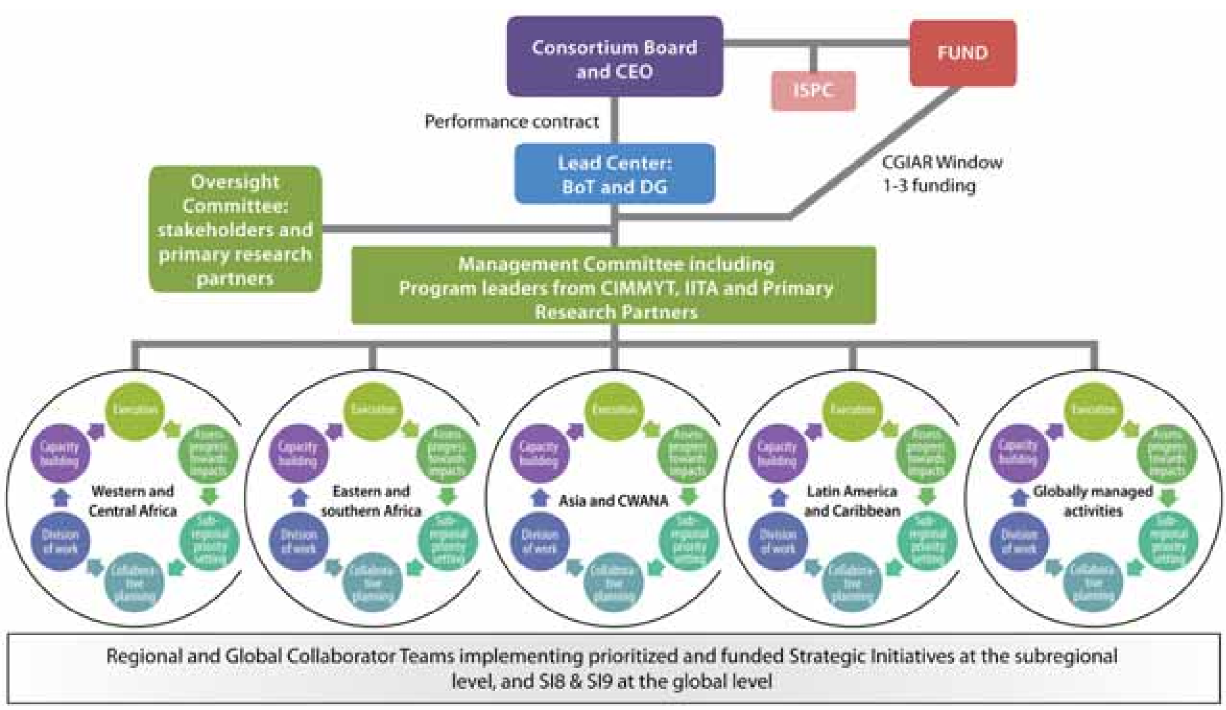

Figure 10. Oversight and management of MAIZE.

Based on current staff and partner networks, MAIZE will be facilitated in West & Central Africa by IITA, and in the other three regions by CIMMYT in collaboration with established sub regional Steering Committees who decide on fund allocations to partners. CIMMYT will also facilitate the implementation of the global Strategic Initiatives SI 8 (Seeds of discovery) and SI 9 (New tools and methods for NARSs and SMEs).

Once priorities and engagement in various Strategic Initiatives are established at the regional level, the MAIZE Management Committee will be responsible for ensuring effective functioning of cross-regional interactions around specific Strategic Initiatives, thus deriving benefit from economies of scale while involving those regions where a particular Strategic Initiative has been prioritized and funds are available.

Definitions of partners

The Program structure depends on various types of partner. MAIZE is contracted by the **Consortium Board** to CIMMYT as **the Lead Center.**

Primary Research Partners are selected institutions which through their mission, skills and resources, provide major research contributions to MAIZE and dedicate significant staff and resources to the Program. CIMMYT and IITA are the founding Primary Research Partners. Additional selected institutions that provide significant international commitment and resources to MAIZE will be included as CGIAR-external Primary Research Partners. Discussions are ongoing with three potential Primary Research Partners: (1) the Secretaría de Agricultura, Ganadería, Desarollo Rural, Pesca y Alimentación (SAGARPA) in Mexico as the upcoming largest contributor and research partner to MAIZE; (2) the Kenya Agricultural Research Institute (KARI) in Kenya, as the largest current research partner in MAIZE; and (3) the Syngenta Foundation for Sustainable Agriculture (SFSA), a not-for-profit organization that links MAIZE with research capacities in the multinational private sector.

Research Partners and **Development Partners** are awarded performance contracts because of their ability to provide specific, high-quality, complementary inputs to MAIZE. Total funding to partners in MAIZE exceeds the total amount of unrestricted funding provided by CGIAR Window 1-3 and is increasing. Given that bilateral projects are negotiated on a continuous basis, details regarding these numerous partnerships will be included in annual operational plans and reports of MAIZE.

Stakeholder Partners are those that participate in the cycle of priority setting, implementation and review of research-for-development without contractual arrangements.

Roles and responsibilities

The **Lead Center**, through its Board of Trustees and Director General, will be responsible for the successful management and implementation of MAIZE. The Lead Center will provide clear vision, direction, priorities and focus through well-led, inclusive, consultative, and transparent processes; and be a credible convener of partners for the breadth of a CGIAR Research Program.

The **Board of Trustees of CIMMYT** has the fiduciary and legal responsibility and accountability for implementing MAIZE. It will monitor the successful management and implementation of MAIZE, including the effective use of Oversight Committee feedback. Other roles are expected to be reciprocated by **governance or management entities of all Primary Research Partners**. These are to:

- Ensure that their institution's or department's policies, vision, mission and values are in agreement with (i.e. do not contradict) and facilitate the management and implementation of MAIZE.
- Ensure appropriate inclusion of MAIZE in their strategic plans.
- Assume fiduciary and legal responsibility and accountability for implementing performance contracts.

While MAIZE cannot influence the role of governance entities of Primary Research Partners, the very definition of Primary Research Partners ("Providing significant international commitment and resources to MAIZE") implies taking co-ownership in MAIZE and this will be reflected in the institution's or department's actions, support to, and championship of MAIZE.[5]

The Director General of CIMMYT and CEOs or appropriate management units of Primary Research Partners will:

- Support the MAIZE Management Committee and effective collaboration with other program participants in furtherance of MAIZE.
- Ensure high-quality implementation of research and partnership approaches, including the effective integration of existing and development of new bilateral projects.
- Assign appropriate staff to the MAIZE Management Committee, and implement agreed activities as documented by annual workplans and performance contracts.
- Ensure that systems and policies are in place to successfully manage the performance contracts.
- Manage the risks associated with implementing MAIZE performance contracts.
- In the case of CIMMYT and IITA, designate and empower regional coordinators with appropriate seniority and skills to spearhead the implementation of MAIZE in each region.

In addition, the Director General of CIMMYT will:

- Resolve any institutional or personal conflicts among partners that cannot be resolved by the Management Committee, drawing if necessary on support and advice by the Oversight Committee, the CIMMYT Board of Trustees, and the Consortium Board Chair as the last instance.
- Liaise with the Consortium CEO to ensure close understanding of MAIZE by the Consortium Board.
- Represent (or ensure representation of) MAIZE at major global research and development events.

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[5] Such an institutional commitment of Primary Research Partners is different from the implementation of CGIAR Challenge Programs that mostly contracted expertise of individuals from other institutions. The concept of institutional partners has been core to implementing large-scale projects such as the Drought Tolerant Maize for Africa Project as implemented by CIMMYT and IITA in collaboration with 13 partner countries, or the Water Efficient Maize for Africa Project as implemented by AATF, Monsanto and CIMMYT in collaboration with five partner countries.

Oversight Committee: This committee comprises individuals who can bring together state-of-the-art scientific expertise and high-level insights from diverse partners (NARSs, the private sector, ARIs, farmer organizations) and one representative each from the Primary Research Partners. The committee's role is to:

- Broaden the perspectives and views about MAIZE beyond the Management Committee and the Lead Center, without line responsibility.
- Guide the Director General of CIMMYT and the Management Committee on criteria that define successful management and implementation of MAIZE.
- Monitor the overall performance of MAIZE, the relevance of outputs, the feasibility of the 3-year/annual MAIZE workplan and provide such assessments to the Management Committee and the Director General of CIMMYT.
- Advise on opportunities to enhance the performance of MAIZE, strategic alliances with partners, and the effective engagement of partners.
- Periodically review the principles that guide resource allocations between SIs, regions, partners, also the use of internal and external global research-for-development capacities.
- Establish principles that assist the Lead Center DG and CRP Management Committee in conflict resolution.

The **Management Committee** (MC) is the executive committee of MAIZE. This is an executive working committee consisting of the relevant institutional research directors, regional and program leaders from Primary Research Partners, all of whom oversee the implementation of the MAIZE research agenda within their institutions. Management committee composition will remain small (≤ 10). The Committee will be chaired by the Research Director of the Lead Center. It will include external observers until Primary Research Partners are formally confirmed and performance contracts are established. The Committee will meet at least semi-annually and interact bi-monthly through phone or video conferencing. The committee is responsible for the global management of MAIZE and in particular will:

- Oversee and be responsible for the quality and relevance of the outputs produced under MAIZE.
- Enhance the overall performance of MAIZE and assist research teams and research partners.
- Plan scientific delivery of MAIZE outputs through annual and three-year workplans and budgets.
- Recommend the inclusion of additional partners as Primary Research Partners, for the Lead Center to negotiate appropriate performance contracts and agreements.
- Ensure effective engagement of R&D capacities across SIs and regions, and integration among them and with other CRPs.
- Guarantee that innovative partnerships are present across MAIZE and that a coherent gender strategy is articulated and successfully implemented.
- Following the overall principles of budget allocations, optimize use of resources across SIs and regions.
- Resolve internal conflicts (e.g. credit for work done, budget allocations, personnel conflicts etc.) and formally forward those that cannot be resolved to the Director General of CIMMYT.

- Plan the MAIZE communications strategy and guide the implementation of MAIZE Web- and email-based stakeholder interactions, knowledge management approaches, and the collection of M&E information.
- Report MAIZE progress against workplans, milestones, outputs and outcomes.
- Coordinate the bilateral fundraising aligned with the MAIZE strategy.
- Oversee contracts between the Lead Center, other Primary Research Partners and those Research Partners who contribute to MAIZE global activities.
- Seek to fulfill all aspects of the MAIZE performance contract between the Lead Center and the Consortium Board for successful implementation of MAIZE.

Oversight of individual Strategic Initiatives

The oversight of individual or clusters of Strategic Initiatives is assigned to various Management Committee members. Assignment of responsibilities is based on the capacity to lead and in support of the most effective management and implementation across and within SIs. Those responsible for a particular Strategic Initiative should:

- Ensure integration across activities in different regions, identify and promote cross-cutting synergistic research activities.
- Ensure high-quality implementation of activities.
- Facilitate preparation of annual or medium-term plans and budgets.
- Facilitate preparation of annual reports.
- Monitor progress on macro deliverables and highlight bottlenecks to the Management Committee.
- Provide input to the development of new bilateral projects that align with particular SIs.
- Provide regular progress reports to other members of the MC.

Global coordination and facilitation

Global coordination is facilitated by a program management unit associated with the Chair of the Management Committee. The unit will:

- Facilitate the compilation and consolidation of the global MAIZE workplan, budgets, and reports from among members of the Management Committee for approval and submission by the Director General of CIMMYT to the Consortium.
- Execute global performance contracts, subcontracts and MoUs.
- Implement MAIZE-wide web/email-based stakeholder interactions, knowledge management approaches, and the collection of M&E information.
- Facilitate the use of consistent and simple tools across MAIZE, ideally aligned with other CRPs.
- Facilitate collective agreement by the Management Committee, on matters including mechanisms, processes and decision criteria for funding allocations.

Regional and Global Collaborator Teams: Regional and Global Collaborator Teams meet annually in each sub-region or globally, and include crucial outside stakeholders, development partners, and external experts who provide insight on the research agenda. They will:

- Review and refine priorities, targets, progress and impact pathways in view of available resources (of MAIZE and those contributed by partners).
- Agree on research responsibilities of specific partners and the need to involve others.
- Peer review and provide recommendations to annual workplans and budget allocations of partners
- Assess capacity-building needs and other services necessary for the success of the research.
- Jointly monitor and evaluate progress to outputs and outcomes and make adjustments.
- Ensure effective sharing of the knowledge—whether already existing or from MAIZE research—within their region and beyond.
- Discuss opportunities and assign and implement responsibilities for broader diffusion of the knowledge to achieve development impact with a wide range of partners.

Regional coordination and facilitation

CIMMYT and IITA designate and empower a regional coordinator to spearhead the implementation of MAIZE in each region. The regional coordinators will:

- Execute regional performance contracts, subcontracts and MoUs.
- Optimize meetings of research teams and stakeholders at the regional level
- Represent (or ensure representation of) MAIZE at major regional research and development events.
- Coordinate and facilitate regional networking and partnerships, along with advocacy to encourage complementary investments by regional development partners.
- Contribute to building a broad base of stakeholder awareness and support for MAIZE among regional stakeholders.
- Arrange for internal (peer-review) and external evaluation of progress and impact.

Linkages and boundaries with other CGIAR Research Programs

The detailed opportunities and needs for interaction with other CRPs are shown in Table 4. They follow the Strategic Results Framework, outcomes of the Consortium Board-Alliance Meetings (27, 31 March and 01 April 2010, Montpellier, France), and agreements (through email exchange) with each of the CRP facilitators and the Generation Challenge Program (as the facilitator for the Genomics and Integrated Breeding Services [GIBS]). In general terms the linkages and boundaries with relevant CRPs will be as follows.

CRP1 Integrated agricultural systems for the poor and vulnerable. Regarding boundaries with CRPs 1, 3, and 5, MAIZE follows the guidelines of the Strategy and Results Framework (SRF) and conclusions from the meetings of the Consortium Board with the former CGIAR Alliance Executive in March and April 2010. As they pertain to major global food crops that are also drivers for important production systems, GRiSP, MAIZE, and WHEAT were requested to include work on rice, wheat and maize *production systems* (Figure 11). As a result, GRiSP, MAIZE, and WHEAT will focus on and contribute to progress in poverty hotspots where rice, maize, or wheat are dominant crops in farming systems and primary drivers of change to increase food security, farm-level productivity, and environmental sustainability. From the original guidelines, CRP1 was designed to focus on poverty hotspots in more diverse farming systems and where interventions are less likely to be driven by interventions targeting one of the three major food crops listed above. Systems delineation is based on the FAO farming systems classification. For a production system to be included in MAIZE, maize must be the most important crop by area and the system must include a large number of poor. Six prioritized systems that were selected are shown in Annex 1. CRP 1 and GRiSP work with production systems chosen from those where maize is less dominant. In those, MAIZE collaborators will work with the other CRPs where those programs consider maize to be an important component in the systems on which they work, and require input from MAIZE.

CRP2 Policies, institutions, and markets for enabling agricultural incomes for the poor. MAIZE will focus on policy, institutional, and market issues specific to the maize crop and farming systems where maize is dominant. CRP2 will focus on multi-commodity and cross-sectoral issues; it will also support MAIZE with specialized expertise on economic models and policy.

CRP4 Agriculture and improved nutrition for health. Based on priority setting and co-funding by CRP4, MAIZE will focus on generating nutritionally enhanced maize and will partner with CRP4 for technology adoption in specific target countries. CRP4 will also focus on technical and institutional aspects of nutrition, including policy, dissemination, and adoption.

CRP5 Durable solutions for water scarcity and land degradation. The linkage and boundary with CRP5 also follow the CB-Alliance-SRF guidelines shown in Figure 11 and described in the text above on CRP 1. The SRF outlines the central role of cropping systems research for food security and its linkages to natural resource management and climate change adaptation. The focus of SI2 in MAIZE is on practices used in six distinct maize-based systems (Annex 1). The focus of SI3 is on maize-specific measures to increase nutrient and water use efficiency in maize. CRP5 on the other hand will provide integrated information, analysis, and knowledge of water, land, and ecosystems at the basin, watershed, and landscape scales, and with no particular crop focus. It will also provide links to national water and land policies and the global water and environment communities. The focus of CRP5 is on geographic regions where water scarcity and land degradation most strongly impact the livelihoods of the poor. MAIZE will work with CRP5 to ensure positive or neutral ecosystem impacts of MAIZE-promoted interventions and align interventions with CRP5 recommendations and policies.

CRP7 Climate change, agriculture and food security MAIZE will develop technologies and information relevant to the success of CRP7 in climate-change adaptation and mitigation. CRP7 will provide tools, models, scenario analysis, and links to the global climate change community. It will also test MAIZE-generated technologies at its pilot sites and provide expert analysis of the impacts and biophysical and socioeconomic context in which they must perform. Further detail is provided in the “Climate change strategy” section below.

Genomics and integrated breeding service of the Generation Challenge Program GCP’s agenda will transition into the "Genomics and Integrated Breeding Service" (GIBS); components associated specifically with maize (2% of the MAIZE budget) will be integrated into MAIZE. The pioneering genomic research and molecular breeding tools for new breeding applications in SI 8 (Seeds of discovery) and SI 9 (New tools and methods for NARSs and SMEs) will become major drivers for the GIBS.

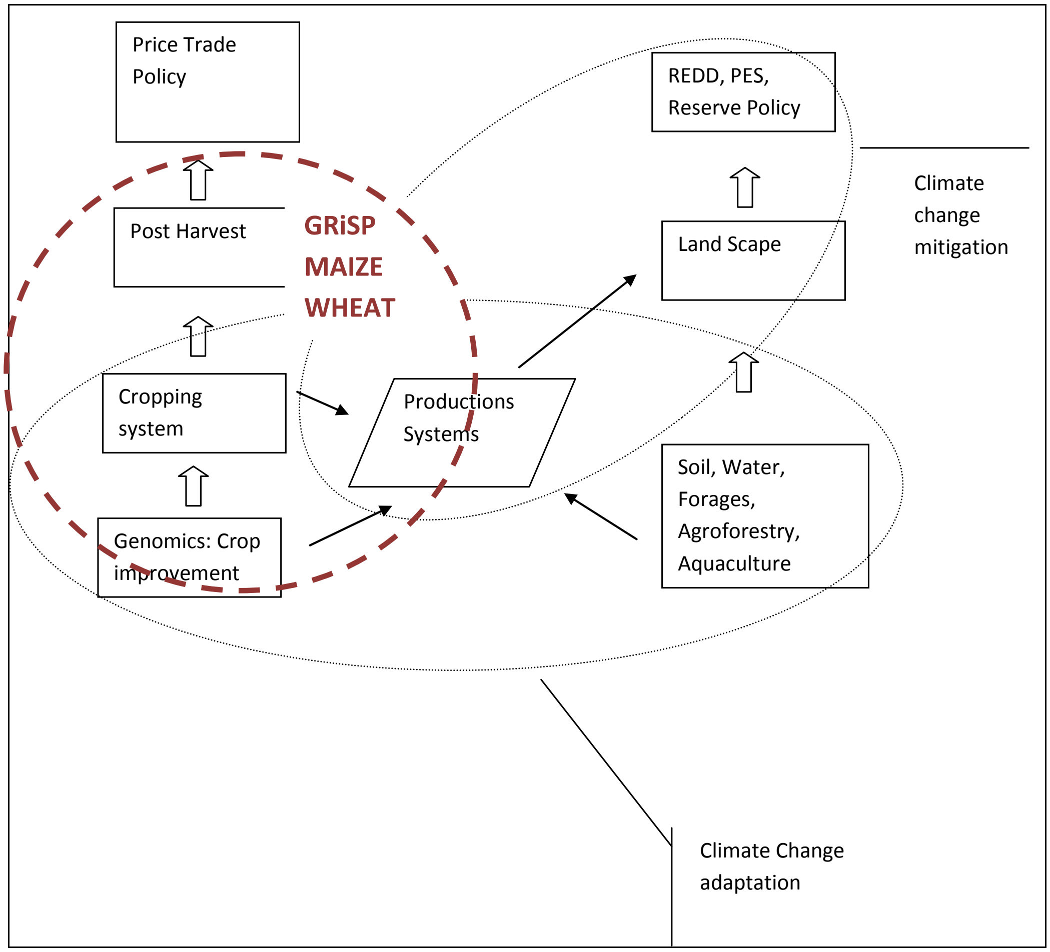

Figure 11. Core competencies of the CGIAR and the role of GRiSP, MAIZE, and WHEAT (CGIAR Strategy and Results Framework, Figure 3.2 [black font] and based on the conclusions from the Consortium Board - Alliance Meetings, 27, 31 March and 01 April 2010, Montpellier, France [red font]).

Table 4. Interactions of MAIZE with other CGIAR Research Programs.

CGIAR Research Program	Outputs from MAIZE to other CRPs	Inputs from other CRPs to MAIZE	Joint actions between MAIZE and other CRPs
CRP 1.1 &1.2. Integrated agricultural production systems for dry areas and for the humid tropics.	Enhanced germplasm and innovative practices, including precision agriculture and postharvest management, insights from value chain (e.g. seed sector) are integrated according to their contribution to diversification, intensification, productivity, efficiency, profitability, and sustainability.	Feedback on needs for, and performance of maize-specific components in complex systems.	Exchange on priority research sites and approaches to prevent duplication and foster optimal sharing of insights.
CRP 2. Policies, institutions and markets to strengthen assets and agricultural incomes for the poor.	Information on households, productivity and value chains as input to market and welfare models; maize-specific gender analysis; genetic technologies that provide high-value opportunities such as specialist products for smallholders and the agro-industry. Maize-specific impact assessments and socioeconomic analyses.	Strategic foresight on markets; evaluated institutional innovations for delivery of market information and services to small maize producers; tested new methods of value chain analysis. Trend analysis and scenarios for poverty, markets, risk and environment. Models and tools for impact assessment; GIS information.	Improved policies, institutions and market relationships that integrate maize producers into value chains Cross-country analyses of production and technology policy in maize-based systems Joint research on maize futures.
GRiSP in CRP 3. Global rice science partnership.	Maize-specific germplasm, practices and information.	Feedback on needs for, and performance of maize-specific components in rice-maize systems, especially in South Asia.	Joint research on rice-maize systems.
Dryland cereals in CRP3. Food security and growth for the world's most vulnerable poor.	Drought breeding methodologies developed in SI 4 and SI 9.		Exchange of experiences on breeding methodologies, markers and genes associated with drought tolerance.

CGIAR Research Program	Outputs from MAIZE to other CRPs	Inputs from other CRPs to MAIZE	Joint actions between MAIZE and other CRPs
CRP 4. Agriculture for improved nutrition and health.	Exploration and identification of new traits of nutritional significance; nutritionally enhanced germplasm, breeding approaches and functional markers; insights from gender, value chain analysis that may influence the impact pathway of nutritionally enhanced maize.	Targeting, advocacy and promotion of biofortified maize; approaches that reduce the asset gap between men and women, and empower women to enhance nutrition and health of their family; interventions to increase the consumption of nutrient-rich maize especially by women, children and other vulnerable groups. Identify points where nutrients are lost and gained in the value chain, and potential interventions.	Priority setting for new traits, given opportunities, feasibility and needs; co-funding of technology development and adoption in specific target countries for nutritionally improved maize varieties (essential amino-acids, pro-vitamin A and micronutrients).
CRP 5. Durable solutions for water scarcity and land degradation.	Information on water, land and ecosystem changes associated with changes in maize technology, especially through sustainable intensification of smallholder production, precision agriculture and stress-tolerant maize.	Insights, information and analysis of trends and broader water, land and ecosystem resource management issues, including how drivers of change could influence maize production futures. Links to national water and land policy and the global water and environment communities.	Scaling up results from systems research to the landscape level.

CGIAR Research Program	Outputs from MAIZE to other CRPs	Inputs from other CRPs to MAIZE	Joint actions between MAIZE and other CRPs
CRP 7. Climate change, agriculture and food security.	New maize genetic and management technologies. Germplasm that fits climate change challenges. Pilot and evaluate climate risk management by rural communities. Use of predictive information in maize research. Integration of mitigation options into testing of varieties and management in maize-based systems.	Tools to address climate change context in farming systems. Modeling of virtual crops under changing climate to identify future priority traits. Tools for climate change (CC) risk management and resilient livelihoods for rural communities. Improved prediction of impacts and other climate services . Test feasibility of payments for on-farm GHG mitigation by small farmers. Testing the economic and technical feasibility of GHG mitigation options at landscape level.	Testing of technologies and policies to develop holistic CC adaptation strategies. Priority setting and expert workshops, including for NARESs. Co-finance testing of options in communities. Linking mitigation incentives to new technical options. Verify GHG budgets; co-finance development of technologies that enhance mitigation in specific communities.
GIBS. Genomics and Integrated Breeding Service.	Pioneering research on maize genomics, molecular breeding and bioinformatics provides general principles for cross-pollinated crops.	Pioneering functionality used in other crops provides new opportunities for MAIZE.	Joint planning of investments in genomics, molecular breeding and bioinformatics platforms.

Climate change strategy

The impact of climate change on agricultural production will be greatest in the tropics and subtropics, with Africa and South Asia being particularly vulnerable as a result of the range of projected impacts, multiple stresses and low adaptive capacity (Solomon et al. 2007; Hulme et al. 2001). Across various models, climate change is likely to reduce the productivity of current maize technologies, with the greatest losses predicted for southern Africa (Figure 12). In addition, climate change impact on maize production will increase as the frequency of drought and other weather extremes increases (Figure 3) and—as a recent analysis of CIMMYT International Trials shows—the more frequently temperatures rise above 30^{o}C. Extreme weather events will also alter the incidence, severity and geographical distribution of pests, diseases and invasive weed species, thus affecting the stability of maize productivity. Hence, the development of germplasm to offset expected yield losses under projected climate change scenarios is of upmost importance. Additionally, crop and soil management practices that reduce moisture stress, reduce greenhouse gas emissions and enhance carbon sequestration will have important effects in the adaptation to and mitigation of climate change.

Many of the principal elements of the MAIZE strategy were designed for deployment in future climates and address the needs of people living in future climates. They include:

1. Aligned with CRP7, diagnosis of vulnerability of livelihoods, analysis of adaptation mechanisms including new technologies, policies and institutional strategies (MAIZE SIs 1 & 2).
2. Crop management practices to help adaptation to climate change (MAIZE SIs 2 & 3).
3. Improving heat, drought, and water-logging stress tolerance in maize (MAIZE SIs 4 & 9).
4. Understanding host-plant resistance in maize for emerging insect-pests, diseases, and parasitic plants (MAIZE SIs 4 & 6).
5. Efficient methods for developing cultivars with combinations of stress tolerance to confront changing climatic conditions (MAIZE SIs 4, 6 & 9).
6. Delivery of low-cost hybrids to smallholders in stressed environments (MAIZE SIs 4 & 5).

Also, the CIMMYT and IITA breeding programs are organized around the concept of "mega-environments", i.e. areas with broadly similar environmental characteristics with respect to maize production (Setimela et al. 2005). Similar combinations of climatic and edaphic conditions exist within and across continents, allowing identification of maize mega-environments on the basis of GIS data. As climatic conditions change at particular sites, it will be possible to reassess the mega-environment assignment of the site, guiding breeders to develop appropriate new germplasm for future climates. In addition to the capacity to source germplasm from mega-environments with conditions similar to those arising from climate change in their own areas, SI 9 (New tools and methods for NARSs and SMEs) will enable breeders to rapidly move stress tolerance traits into germplasm preferred by farmers in the target environment they serve.

As a result, agreement has been reached whereby technology development per se would be financed by CRP3, but CRP7 would co-finance the testing of these technologies through adaptive research and action research with farmers. CRP7's commitment is to work with CRP3 partners to define phenotyping and breeding targets for future climates and to offer opportunities for testing CRP3-derived technologies in the context of integrated adaptation-mitigation strategies. This is reflected in the CRP7 proposal re-submitted to the Consortium Board.

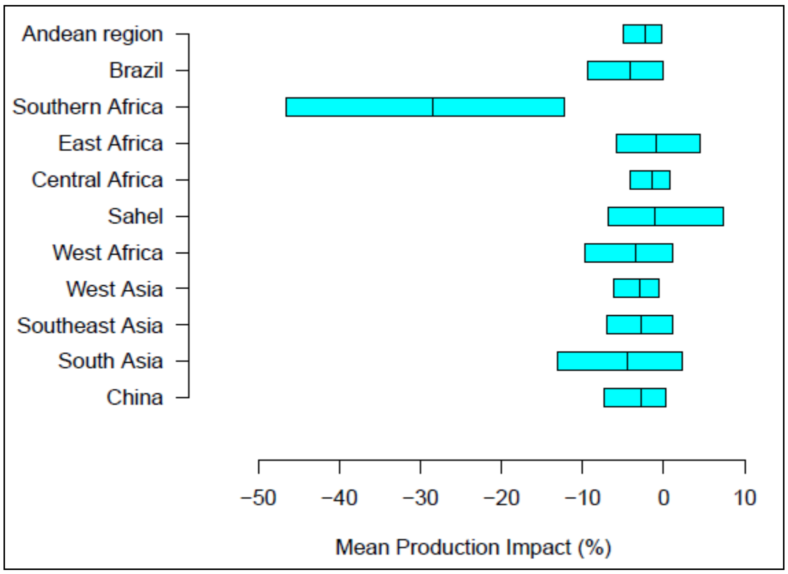

Figure 12. Predicted maize production impacts in 2030 from climate change expressed as a percentage of 1998 to 2002 average yields. Boxes extend from the 5th to 95th percentile of projections and the middle vertical lines within each box indicate the median projections (adapted from Lobell et al. 2008)

Monitoring and evaluation, impact indicators and assessment, priority setting

MAIZE will implement a framework for monitoring and evaluation (M&E) of processes and impact targets from proposed interventions. This will be undertaken at different levels, using established methods for *process evaluation* and *impact assessment* (Baker 2000; Cobb-Clark and Crossely 2003). Priority setting will be informed by targeting and ex-ante socioeconomic analysis of binding constraints and intervention opportunities in each system. A social scientist with skills in M&E and gender analysis will be recruited, to lead the M&E work as well as the institutional learning processes associated with it.

Process evaluation will determine to what extent MAIZE has been implemented as planned and identify operational and strategic lessons for flexible and adaptive management. This will be done through ***process monitoring*** and ***performance assessments*** that will require further analyzing and mapping of activities and impact pathways, in collaboration with partners during inception workshops. These actions will result in an improved definition of milestones, outputs, desirable outcomes and partner roles.

Process monitoring will include participatory reviews of milestones in each region and SI during virtual and annual face-to-face meetings of research partners; and taking corrective measures if milestones are delayed. **Performance assessment** will review the quality and quantity of outputs and outcomes, based on the evolution of Key Performance Indicators (Table 5).[6] Uptake of outputs by clients (NARSs, seed companies, NGOs and extensionists, policy makers) will be a key indicator for the usefulness and quality of the outputs, and will be supported at one-, two- or three-yearly intervals, depending on the nature and extent of the change, using web-based surveys and stakeholder consultations that capture outcome indicators.

Process monitoring and performance assessment will be conducted in a participatory manner (Douthwaite et al. 2007) to emphasize learning and improvements, rather than simply stacking outputs and ticking boxes to show that milestones have or have not been accomplished. If a "failure" to complete a milestone leads to better understanding of the situation being addressed and development of a better way to accomplish the objective behind the milestone, then the initial effort was not necessarily a failure. The participatory approach will also emphasize a multidisciplinary approach to allow unforeseen events (failures as well as unexpected successes) to be reflected upon from different perspectives and better assessment of non-technical factors that condition technology choice, adoption, and adaptation by small-scale farmers.

Impact assessment will be done in SI 1 (Socioeconomics and policies for maize futures) in collaboration with external experts. It will evaluate the success of MAIZE in achieving its stated goals and objectives. It will measure progress using tangible indicators identified by the program, testing how the program output differs from a counterfactual situation without interventions. It will use recent advances in both qualitative (outcome mapping, narrative stories with key informants) and quantitative approaches (econometric, bio-economic modeling, and general equilibrium modeling) to understand the determinants of adoption. It will evaluate the heterogeneous economic, social (poverty and gender) and environmental impacts of interventions on the target groups, offer realistic assessment of returns to investment, and extract useful insights for targeting, up-scaling and priority setting of proposed future interventions (Alston et al. 1995; Wooldridge 2002; Alwang and Siegel 2003; Moyo et al. 2007; Zilberman and Waibel 2007; Shiferaw et al. 2008).

Given research-to-impact timelines, farm-level impact assessments during 2011–13 will focus on establishing baselines and monitoring adoption in three primary project intervention areas in SI 2 and on assessing past and on-going impacts for SI 4 and SI 5. This will be in addition to a rigorous gender audit done for the entire MAIZE agenda. Impact assessment during 2014–16 will focus on SI 2, SI 3, SI 6, and SI 7, while SI 8 and SI 9 will only be monitored at the level of output and outcomes.

[6] In addition to technical performance indicators, generic key performance indicators (KPIs) based on institutional financial reports will be prepared in accordance with international accounting standards, which measure aspects such as liquidity, financial stability, organizational efficiency, and planning and investment capability. Risk management and organizational KPIs, while useful, are less standardized than financial KPIs and therefore need to be interpreted with more caution. In addition to using such KPIs, the Lead Center will commission its own yearly organizational audit from management and risk-assessment experts who would report their findings and recommendations to management as well as the Oversight Committee.

Table 5. Key Performance Indicators.

#	Indicator	Strategic Initiative									Disaggregation meaningful by		
		SI1	SI2	SI3	SI4	SI5	SI6	SI7	SI8	SI9	Gender	Country	Insti-tution
		Targeting & policies	Systems	Agronomy	Stress tolerance	IMIC	Post-harvest	Nutrition	Diversity	Tools			
1	Number of documents/research articles and databases improving the **definition of target area and farmer needs**	Yes	Yes	Yes	Yes	Yes	Yes	MP4			Yes	Yes	
2	Number of **users using MAIZE Portal, or accessing web-based databases or CD's** documenting germplasm, trial or socio-economic data, training modules, e-learning or IT tools	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	
3	**Number of protocols** for improved phenotyping, selection strategies, crop & systems management options developed, validated, communicated to, and implemented by partners	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes	Yes
4	Number of institutions involved in **collaboration for research and capacity building**, including farming communities	Yes	Innovation hubs	Diagnostic trial	Open source-breeding (OSB) or phenotyping				Genotyp., Phenotyp	OSB	Yes	Yes	Yes
5	Number of collaborative **trial sets planted and reported**		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
6	Number of **germplasm (inbreds/hybrids/OPVs, genetic resources, introgression lines) developed and distributed** to partners on request				Yes	Yes	Yes	Yes	Accessions, Introgression lines	Inducer, AM Panel		Yes	Yes
7	Measures for genetic **selection gains** achieved every second year				Yes	Yes	Yes	Yes		Yes			
8	Number of **variety releases**				Yes	Yes	Yes	Yes				Yes	Yes
9	Quantity of **seed of hybrids/OPVs** up-scaled by partners				Yes	Yes	Yes	Yes				Yes	Yes
10	Number of **institutions joining IMIC** and subscribing to the web platform					Yes						Yes	Yes
11	**Germplasm bank accessions maintained**								Yes				
12	Number of **varieties characterized on a molecular level** by genotyping and sequencing								Yes	Yes			
13	**Documents/reports indicating use** of MAIZE germplasm, tools, information	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
14	**Number of clients trained**: national program staff, scientists, technicians, seed companies, teachers, extension agents, students etc	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15	**Number of farmers/beneficiaries interacting** with MAIZE-implemented research through field days and other forms of awareness	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
16	**MSc/PhD students graduating**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
17	**Number of publications:** (1) open access publications (full text), (2) peer reviewed journal articles	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
18	Number of **institutions with upgraded infrastructure**: newly established or improved phenotyping platforms, labs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes

Given the high costs and difficulties of establishing counterfactuals in the field, data will be analyzed using propensity score matching (PSM) and double difference methods, which will help control for potential sample selection biases in evaluating the impacts of program interventions. The PSM approach will help identify a matched sample of non-adopters (a comparator group having similar observable characteristics as adopters) which will serve as a counterfactual to estimate the attributable impact of the project on adopters (treatment group) [7].Where panel data before and after the project are available from the treatment and comparator groups (such as in SI 2 but less likely in SI 5), the double difference method will be used to evaluate the impact of the interventions. This can also be combined with PSM to control for matching on non-observable factors (Wooldridge 2002). This will be supported by instrumental variables and other regression methods that help control for selection and endogeneity bias in program participation.

Impact indicators

The **first order impact** indicators for MAIZE will include: changes in technology adoption; changes in crop yields, area, and production; changes in practices and level of inputs; changes in production costs and profitability; changes in institutional capacity and policy; changes in attitudes and risks faced by farmers; empowerment and reduced workload for women. The **second order impacts** that may result in the long term will include: changes in the welfare of producers and consumers due to permanent income, asset accumulation, and price effects; changes in consumption, food, and nutritional security; changes in distributional impacts (different wealth groups, marginal farmers, women, and workers); changes in social conditions (poverty, education, health, attitudes, role of men and women in society); changes in resource management and environmental conditions; other spillover and indirect economy-wide effects.

All M&E and impact data will be disaggregated by gender and regionally appropriate wealth indicators to understand the distributional impacts and determine whether project benefits are reaching targeted demographic groups. The major findings from process and impact evaluation studies will be compiled and shared widely among R&D partners and external reviewers to inform and influence future courses of action. Alternative platforms including project websites, scientific publications, review meetings and regional workshops and conferences will also be used to share findings.

Priority setting

Targeting and ex-ante socioeconomic analysis undertaken by SI 1, together with systematic interaction with partners and feedback from clients, beneficiaries and R&D partners, will be crucial for improving our understanding of the context, constraints and high-payoff research strategies. It will also permit the MAIZE Management Committee to adjust resource allocations to and within various SIs, thereby shaping priorities and enhancing the relevance and quality of MAIZE. Priority-setting and review will be

[7] In experimental studies, this problem is addressed by randomly assigning households to treatment (technology adopters) and controlled groups (non-adopters) status, which assures that the outcomes observed on the controlled groups without adoption of agricultural technology are statistically representative of what would have occurred without adoption on the treatment households.

implemented through SI-specific ex-ante impact analysis, expert panels, workshops, web platforms and other means. Impact pathways for each SI will be developed and regularly adjusted with partners to foster the desired changes and draw lessons for scaling-out of the project's successes. Geo-referenced data sourced from various CRPs and other SI-related data will provide regular updating of impact pathways and document the likely impacts of introducing available technologies, the recommendation domains for different varieties and management practices, and projected impacts on poverty and gender groups. These data will be shared with project partners and policy makers in target areas. In preparation for a new phase proposal, this will be followed up by ex-ante assessments of opportunities for future research-for-development investments (to be undertaken as part of SI 1).

Intellectual property management

Networking is our strength

Each MAIZE Strategic Initiative relies on collaborative and participatory networks designed to generate outcomes for clients and impacts for beneficiaries. Partnerships are being forged among international centers, ARIs, NARSs, regional organizations, farmer and civil society groups, private enterprises, donor organizations and governments at various points of the maize value chain. These partnerships will develop and disseminate higher-yielding, more nutritious, stress-tolerant and disease-resistant cultivars, foster more productive, resilient, and sustainable production systems, and impart knowledge as global public goods.

Intellectual property as a tool to enable research and to reach clients

Intellectual property (IP) management is an enabling tool to generate and disseminate global public goods. In all its partnerships, including public-private, MAIZE will actively source the best technologies as inputs to accelerate R&D implementation, speed deployment of global public goods as outputs, and increase humanitarian impact. Our core approach in all collaborations includes upholding the rights to perform Research, Development, and Deployment (RDD), using both inputs and outputs and insisting on the unrestricted access to R&D outputs by target countries, clients and beneficiaries.

Pre-competitive and competitive domains

The multiple RDD collaborative networks in which MAIZE participates build a pre-competitive RDD domain that encourages open availability and strong collaboration for R&D in bio-components, knowledge and tools as inputs for the development of global public goods. During its implementation, MAIZE will encourage such a "pre-competitive ag-commons" to the greatest extent possible. In many instances, however, a competitive domain is required to market products from outputs of the pre-competitive domain. Commercial enterprises both large and small contribute to the dissemination, deployment and uptake of maize agricultural solutions by farmers and consumers in target countries.

By employing market instruments such as registration and certification schemes, protected IP rights and contracts, and non-restrictive business practices, the commercial partners play a key role in increasing the uptake of outputs and the intensification of much needed follow-on innovation with global spillover effects. In accordance with international regulations on plant genetic resources, the implementers of MAIZE will thus strive for (and foment through IP management) a healthy combination of collaboration and competition in agricultural RDD—to bridge the gap between generated seeds and technologies on one hand and their efficient uptake by diverse clients on the other hand, thereby generating the intended beneficial impacts on food security, poverty reduction and environmental sustainability.

Regulatory frameworks for innovation in targeted regions
Regulatory frameworks for intellectual property, seed and biosafety in target countries and markets could represent either a friend or a foe to the adoption of or access to MAIZE products. Policies and rules posing barriers to (non-)transgenic varietal release, registration and commercialization may halt an otherwise successful innovation process and prevent sorely-needed impacts. MAIZE will work actively with pertinent regulatory authorities to: arrive at a mutual understanding of biological and technical issues, seed markets and regulatory frameworks; train and build capacities of researchers and authorities with regard to biological knowledge; advocate for the adoption of adequate regulatory standards and measures; devise innovative and feasible mechanisms that facilitate entry of public-sector transgenics into current costly, unreachable markets for certified and transgenic crops.

Germplasm distribution
All maize germplasm distribution from CIMMYT and IITA will use the Standard Material Transfer Agreement of the International Treaty on Plant Genetic Resources for Food and Agriculture (www.planttreaty.org)—even though in certain circumstances further conditions and restrictions may apply, based on research agreements that enabled the development of a certain product. For instance, germplasm containing valuable commercial proprietary traits may be subject to temporary or geographical restrictions. Such temporary conditions may be required to provide a competitive advantage to entities adopting and adapting the same traits in a semi-commercial or commercial settings. In all cases, MAIZE will ensure that products emerging from such temporary or geographical competitive domains reach and benefit a significant number of poorer farmers. MAIZE will not engage in collaboration or research agreements that do not promise substantive benefits for poorer farmers, and will withdraw from collaborations that fail to deliver on such benefits or expectations.

Transgenic technology and use of within-species variation

Over one-quarter of the 158 million hectares of maize grown globally in 2009 was transgenic (James 2009). Several transgenic maize products have been developed and released in the USA, mostly by multinational companies. A series of transgenic maize products are in the pipeline for release by public and private institutions in developing countries, most prominently insect and herbicide resistance traits and their combinations ("stacks"). New productivity-enhancing traits, targeted at increasing drought and nutrient-use efficiencies, are in the pipelines of several companies—yet none of them has yet been marketed.

MAIZE recognizes the significance and potential of transgenic technology for improving the productivity, food security and livelihoods of maize producers in the developing world, particularly in situations where genetic variability within the species is limited or novel genetic variation is needed to solve intractable problems. ***But the major emphasis of the MAIZE germplasm improvement strategy will continue to be the exploitation of native genes or allelic variation found within the species.*** This is largely because of the enormous costs of developing transgenic varieties; resources that are usually better spent on more cost-effective, simpler technologies. Also in many instances, native genetic diversity is available and much more relevant than that from transgenic sources. Where transgenic approaches are used, traits targeted may include abiotic stress tolerance, input use efficiency, herbicide resistance, nutritional quality improvement, and biotic stress resistance. The usefulness of each will be assessed on the basis of their merit for smallholder farmers.

In the development, validation, regulated deployment and stewardship of transgenic events for smallholders in Africa, Asia and Latin America, MAIZE will adhere to and foster effective implementation of relevant national and international biosafety rules and regulations. Without exception, transgenic approaches will be pursued only in countries with mature and functioning regulatory systems that support the safe release of transgenic crop varieties.

The significance of partnerships and the progress so far

The development and regulatory approval of transgenic maize varieties is an expensive and complex undertaking involving many steps. These include: identification of relevant gene(s); formation of constructs; transformation producing hundreds or thousands of "events"; identification of specific events with stable and desired levels of expression; wide-scale efficacy and biosafety testing of identified individual events; introgression into elite adapted germplasm; testing of final products under controlled conditions (small-scale experimental field-level testing with appropriate monitoring); approval by regulatory agencies for large-scale release and cultivation in farmers' fields; post-release monitoring to ensure safe, legal and sustainable use of the GM variety.

Total costs for the entire process, from discovery/development to release to farmers, range between USD 25 and 100 million. This is often beyond the capacity and budget of national and international non-profit R&D organizations and small or medium-scale companies. Large multinational corporations have a clear comparative advantage but little incentive to make their products available to poor smallholders—except for market development purposes in transition countries where smallholders are anticipated to become part of an attractive commercial market in the near term. Innovative partnerships are therefore required to ensure that beneficial transgenic events under development for commercial markets are also made available to farmers who do not constitute a large enough market to attract private sector investment.

CIMMYT has developed such partnerships, supported by the Bill & Melinda Gates Foundation with Monsanto and the African Agricultural Technology Foundation (AATF), to deliver transgenic maize hybrids with improved drought tolerance (under the ongoing project *Water-Efficient Maize for Africa—WEMA)*, and with Pioneer Hi-Bred (under the ongoing *Improved Maize for African Soils—IMAS)*, to deliver hybrids with improved yield under conditions of extremely low nitrogen fertility. These projects can serve as models for MAIZE transgene development efforts. They use humanitarian support to move events destined for commercial markets into African-adapted germplasm. Work on gene introgression, variety development, and testing is shared among the companies, CIMMYT and NARSs. Products are made available to poor smallholders through humanitarian licensing arrangements, wherein private partners forgo royalties or technology fees in target countries. These examples show that private partners are eager to participate in such projects so that their proprietary technologies can benefit poor smallholders—increasing their productivity, incomes and eventually their ability to profitably purchase hybrid seed and other inputs.

The comparative advantages and roles of CIMMYT, IITA, and public and private sector MAIZE partners in transgenic variety development and deployment currently comprise the identification of relevant problems requiring transgenic solutions, testing of events under appropriate conditions, sourcing of elite germplasm for transgene introgression, and the development of broad scientific and development partnerships required for successful transgene deployment in target countries. MAIZE will only engage in public-private partnerships (PPPs) supporting transgenic variety development after careful needs assessment, determination of availability of relevant solutions that will likely meet a high level of acceptance, and a rigorous cost-benefit analysis.

Communications strategy and knowledge management

MAIZE will rely on effective bi-directional interaction with stakeholders, including clients (researchers, information and technology providers, policy makers, leaders, and other development partners), target beneficiaries (farmers, consumers, the public) and investors.

In addition to employing well-established mechanisms—socioeconomic and client surveys, trial data, workshops, site visits—MAIZE will use active and passive input to Web platforms and cell phone technology to expand the range of opportunities for obtaining systematic feedback from clients and beneficiaries on the quality and relevance of its products. An example of implementing new feedback mechanisms in the current agenda is the use of ICT tools, as described in SI 3 and SI 5. Process evaluation and socioeconomic surveys will contribute to adjusting feedback approaches and capturing most relevant mechanisms as part of KPIs.

One of the major emphases of MAIZE will be to communicate, educate, and increase the awareness of development partners about products and their availability—using the Web, publications, policy papers, trial summaries, germplasm information, e-based learning modules and meetings (all of which are components of various SIs and which will be linked through a common user-friendly MAIZE Portal, managed by one position assigned to overall MAIZE management. While it is understood that development partners will make the greatest investment in scaling out products and communicating with the wider farming community, MAIZE will make strategic use of local and international news media, simple ICT tools and posters, to increase the demand of beneficiaries and policy makers for those products.

To ensure an enabling environment for its success, MAIZE will use available media (e.g., print and e-publications, Web tools and social media) and contract public relations specialists to target diverse, segmented audiences (e.g., policymakers, research directors, the media, the general public) with timely and pertinent information highlighting the relevance of the MAIZE agenda to public concerns—such as those reflected in the Vision of Success, and others that emerge.

Assumptions

Policies and institutions

1. Unforeseen circumstances, such as soaring global prices associated with unprecedented demand for maize for bio-energy and socio-political unrest, do not offset benefits from value chain integration or diminish the impact of interventions.
2. Governments and development partners internalize the gender-sensitive and pro-poor policy recommendations and institutional innovations that promote equitable access to technologies, inputs and services.
3. Political conditions in partner countries permit effective functioning of NARSs and seed companies, including unimpeded access to field sites.
4. Prices of fertilizers and other inputs do not escalate so much that their application on staple crops is no longer feasible for smallholder farmers.
5. Policies supporting streamlined and accelerated variety release across regions and low-cost seed options will be implemented by governments.
6. Private companies, including those involved in seed business and information and communication technologies, will collaborate for the benefit of small farmers in the developing world.
7. Sufficient high-quality personnel can be recruited to staff research programs in Africa, Asia, and Latin America.
8. Farmers, consumers, and decision makers become aware of, and consider, food safety as an important component of food security and trade enhancement.
9. Conducive policies and supportive institutions continue to focus on food safety as an important component of food security and trade enhancement.
10. Partner institutions agree with the Vision of Success and assist in fine-tuning impact targets.
11. Collaboration between institutions is not impeded by bureaucracy, and research collaboration between CG centers and research partners is facilitated through the Consortium.

12. Decision makers understand and agree with the need to increase the investment in international agricultural research for important food crops.
13. Research and development institutions implement staff policies that motivate, reward and retain highly-trained personnel.

Technologies

14. Transgenes that have proven effective in improving drought and nitrogen stress tolerance in temperate environments and genetic backgrounds will have similar effects under severe stress in tropical conditions.
15. Genes with large and consistent effects on water-logging, heat tolerance and nutritional traits exist, and effective screening methods for heat tolerance can be implemented.
16. The Global Phenotypic Network and the Diagnostic Trial are properly coordinated, with no seed/data-tracking errors or poor trial designs, no lag in flow of information and adequate precision of data.
17. The doubled haploid inducers developed at CIMMYT in tropical/subtropical genetic backgrounds are effective under different environments in the developing world.
18. Seed can be exchanged across country borders in reasonable timeframes and at reasonable costs.

Intellectual property

19. Multinational companies and advanced research institutions are willing to affordably license genes and traits for the benefit of a large number of smallholder farmers.
20. The diversity data/knowledge generated from the SIs is properly protected from appropriation by proprietary interests.

Risks

Given the broad regional and technical components of the CRP, it is considered that only global problems could affect the success of the CRP as a whole—not, for example, national crises or particular technology developments within an individual SI. The three most significant global risks facing MAIZE as a whole are:

1. ***Financing risk*** A global financial crisis could lead to greatly reduced funding for the CRP (<75% of budget). Other possibilities are political pressure to cut aid financing. *Mitigating approach*: develop both public and private sources of funding, and both Consortium and non-Consortium sources; broaden sources of finance.
2. ***Implementation risk*** For implementation risk to affect the CRP as a whole, it would need to be related to the overall management and oversight of the CRP, not to particular countries or SIs. Such implementation risk could include inept or seriously inefficient CRP management combined with inept or seriously inefficient oversight functions. *Mitigating approach*: strong monitoring and evaluation, both within the Consortium as well as independently of the Consortium; broad-based advice and feedback opportunities; effective approaches for decision making and conflict resolution.
3. ***Risk of a "domino effect" failure*** A particular failure of the CRP in a particular area, while not CRP-threatening in and of itself, could conceivably be blown out of proportion to affect the CRP as a

whole. For example, if a GM product released by the CRP is widely publicized in the international press as being harmful, this could threaten the CRP as a whole, regardless of the true severity of the problem. *Mitigating approach*: strong safety and control standards for product releases, coupled with a steady and reliable communications function.

Evolution strategy for MAIZE

The challenges to maize food security and sustainable livelihoods in Africa, Asia and Latin America are diverse and complex, and cannot be effectively addressed in a limited time span of six years (2011–2016). Also, the available budget may impose a serious constraint, allowing work to reach only a limited number of target clients/countries for various Strategic Initiatives proposed. Therefore, the “evolution strategy” (a phrase better suited here than “exit strategy”) for MAIZE will be based on three major components:

1. Dissemination of improved maize technologies in selected target countries/regions
2. Scaling up and out of methodologies and technologies beyond countries reached through MAIZE Phase I (2011–2016)
3. Strengthening the knowledge base and capacity of local/regional institutions/professionals/change agents/farmers

Dissemination of improved maize technologies in selected target countries/region. The products of research undertaken through MAIZE will be disseminated through a wide range of research-for-development partners (public and private), many of whom have had strong linkages with CIMMYT and IITA in the past. Especially important will be the development of local innovation systems that focus the comparative advantages of multiple stakeholder agents on knowledge development, and the generation of more productive and sustainable farming systems in agricultural communities. Innovation systems will be complemented by efforts to improve access to good quality seed by smallholder farmers in the target countries of Africa, Asia and Latin America, especially through the private sector. MAIZE will also put a strong emphasis on a consortium approach to support NARSs and SMEs in developing their own proprietary inbreds, hybrids and OPVs.

Scaling up and out of methodologies and technologies beyond countries reached through MAIZE Phase I (2011–2016) MAIZE research products will become available as international public goods accessible to a wide range of stakeholders, and improved geospatial and socioeconomic information will allow an increasingly improved definition of recommendation domains for research products. However, partnerships and collaborative implementation remain the most effective approaches for rapid and effective availability, uptake and adaptation of international research products, particularly since many of them require significant in-depth knowledge or financial strength for local adaptation. This favors countries and regions where collaboration can be funded due to the interest of donors, and may exclude others from benefiting from international public goods. As a result, additional resources need to be sought to systematically widen the reach of MAIZE.

Strengthening the knowledge base and capacity of partners MAIZE will build the capacity of partners by strengthening the knowledge base, research infrastructure and human resources of local institutions. Capacity building is done as part of implementing MAIZE, whereby research-for-development partners gain experience and expertise in real situations, enabling them to link these with the theory imparted in more formal learning situations. MAIZE research activities will also be used for capacity building and training of young scientists and change agents from other regions with similar challenges. Such capacity building, coupled with mentoring and some support of these scientists once they return to their home countries, can result in their serving as “infection points” for scaling up methodologies and technologies.

Budget

General Strategy

Decisive investments in MAIZE by the international donor community are needed for four main reasons:

1. Continuing poverty and malnutrition in globally important maize-based farming systems, as evidenced by one-third of all malnourished children living in such systems (Hyman et al. 2008).
2. The potential erosion of purchasing power of 900 million poor maize consumers due to escalating food prices and doubling maize demands (Rosegrant et al. 2010); food price increases that exceed income increases of the poor may trigger social unrest and depress economic growth of low and middle income countries.
3. Significant maize production fluctuations that are fostered by the crop's frequent and likely increasing exposure to drought (FAOSTAT 2010); maize production fluctuations may trigger significant maize price fluctuations and commodity price speculations beyond longer-term price trends.
4. The accelerated encroachment of maize—as the dominant crop world-wide—into tropical forests and other fragile ecosystems, to the detriment of crop and biodiversity, soil productivity and climate change mitigation (FAOSTAT 2010).

For MAIZE to mitigate these trends and make a pronounced positive impact on production, people, value, food security, and the environment, as summarized in Table 2 and Figure 8, an estimated investment of USD 61.2 million in 2011, rising to USD 97.8 million in 2013, is required.

MAIZE partners will seek to raise these funds, through:

- Support from the Consortium via the CGIAR FUND.
- Bilateral funds that are aligned with the MAIZE strategy while not conflicting with the Consortium's fundraising strategy.
- Strategic alliances with other institutional research partners whose missions, complementary skills, capacities, and other resources provide significant opportunities for increased innovation, investments, accelerated development and greater impact, in significant components of the MAIZE agenda.

Financing Scenarios by the CGIAR

The CGIAR and its members are at this stage unable to commit to fully fund MAIZE. Two CGIAR financing scenarios are submitted for consideration:

1. Scenario 1 "CGIAR Baseline 5%".
2. Scenario 2 "CGIAR Baseline 5% + New Management".

Bilateral funding: Following the Consortium's guidance, Scenarios 1 and 2 assume that bilateral funding increases by 5% annually, using 2011 as a base. Estimates for 2010 and 2011 are aligned with those compiled by the Consortium in October 2010 and include confirmed contracts. A 5% annual increase in bilateral funding beyond 2011 is a conservative estimate, given that bilateral funding increased 34% in 2010 (current budgets) and 21% in 2011 (current contracts, and contracts whose total value has been confirmed by donors but are not yet signed). As a result, there is good reason to assume that a 5% growth can be achieved, and more. Once clarity is obtained on who participates in "CGIAR Fund mechanisms", bilateral funding may be divided between members and non-members.

CGIAR Window 1-3 unrestricted funding: Scenario 1 assumes that CGIAR Window 1-3 unrestricted funding increases annually at 5% over 2010 and also provides all management costs associated with CGIAR Window 1-3 funding**.** Scenario 2 assumes that CGIAR Window 1-3 unrestricted funding increases annually at 5% over 2010 and also provides all management costs associated with implementing MAIZE.

The summary results of the two scenarios are presented in Table 6, with more details provided for each scenario in Tables 7A and 7B. Scenario 1 and 2 bring MAIZE to 68% and 72% of full funding with proportions of CGIAR Window 1-3 funding of 23% and 26%, respectively, as compared to a current level of 28% in 2009 and 24% in 2010.

Table 6. Funding scenarios for MAIZE.

million USD over three years (2011 - 2013)	**Scenario 1**	**Scenario 2**	**Full funding**
Total Budget	162.0	170.1	237.8
Total Budget in proportion of full funding	68%	72%	100%
Total CGIAR Window 1-3	36.6	44.7	
Proportion CGIAR Window 1-3	23%	26%	
Total Bilateral funding	125.4	125.4	
Proportion Bilateral	77%	74%	

Scenario 1 is a risky option and somewhat contradictory to the CGIAR reform principles. It assumes that new CGIAR mandated management costs estimated at 6% (2% systems costs + 4% CRP management costs) can be recovered from bilateral funding. This may not be the case in particular since *existing contracts* may not be changed and the proposed reallocation will be from research to increased oversight and management. This would put the implementation of MAIZE at risk due to lack of funding for the CGIAR mandated oversight and management components. MAIZE has proportionally very low levels of unrestricted funding (24% in 2010, compared to the 33% CGIAR-wide average) and shortfalls could not be absorbed by unrestricted funding even if such permission were given. To put it into perspective, the new CGIAR costing approach requires MAIZE to invest an amount that is equivalent to 27% of unrestricted resources into new CGIAR mandated management. MAIZE-wide streamlined management approaches have great potential to reduce oversight and management costs in the medium term but lack of investments into the transition period may curtail this ability. Also with higher investments in management during this transition phase, research investments would barely stay at par with inflation.

Scenario 2 proposes that all CGIAR mandated management costs of implementing MAIZE be paid through CGIAR Window 1-3 unrestricted funding in this transition period beyond an annual CGIAR Window 1-3 unrestricted budget increase of 5%. To the extent that management costs can be recovered from bilateral donors and projects, they will be charged to bilateral projects and CGIAR Window 1-3 funding freed up for research. This scenario keeps the CGIAR Window 1-3 unrestricted proportion of funding at current levels of 26%, which is still below the CGIAR-wide average of 33%. This scenario enables MAIZE to be implemented at 72% of the total funding needed and ensures that the budget for managing MAIZE is available to lead it through a transition period where a rationalization of management activities between MAIZE and bilateral projects can be pursued. It is a realistic scenario.

Expenses

Tables 7A and 7B show the optimal allocation of expenses by Strategic Initiative, Region, Institution or Program, Category and also further break-downs of MAIZE management costs.

Table 7A. Income and expenses for Scenario 1 "CGIAR Baseline 5%"

Scenario 1 "CGIAR Baseline 5%"	2009	2010	2011	2012	2013	Total 2011-13	Percent 2011-2013	Comments
Income								
CGIAR Window 1-3: Research	9,434	10,424	10,945	11,493	12,067	34,506	21%	5% increase 2011-13
CGIAR Window 1-3: CRP Management	0	0	438	460	483	1,380	1%	
CGIAR Window 1-3: Consortium Board/FUND	0	0	219	230	241	690	0%	
Bilateral funding, secured	24,380	32,778	24,565	15,688	10,528	50,782	31%	
New bilateral funding (pipeline)	0	0	15,218	26,084	33,333	74,634	46%	
Total	**33,814**	**43,202**	**51,385**	**53,954**	**56,652**	**161,992**	**100%**	**67% of full funding**
Total CGIAR Window 1-3	9,434	10,424	11,602	12,182	12,791	36,576	23%	
Total Bilateral funding	24,380	32,778	39,783	41,772	43,861	125,416	77%	5% increase 2012-13
Proportion CGIAR Window 1-3	28%	24%	23%	23%	23%	23%		
Expenses by Strategic Initiative			**Optimized allocation**					
SI1 Socio-economics	2,239	4,332	5,989	6,288	6,603	18,880	12%	
SI2 Systems intensification	4,000	7,704	8,512	8,938	9,385	26,835	17%	
SI3 Yield gap	412	607	1,444	1,516	1,592	4,552	3%	
SI4 Stress environments	14,449	19,126	9,558	10,036	10,537	30,131	19%	
SI5 Double yield	2,556	3,343	5,818	6,108	6,414	18,340	11%	
SI6 Post harvest	1,422	1,790	3,393	3,563	3,741	10,696	7%	
SI7 Nutrition	2,088	1,733	675	708	744	2,127	1%	
SI8 Genetic diversity	2,470	2,303	7,013	7,364	7,732	22,110	14%	
SI9 Tools	2,758	1,407	2,521	2,647	2,780	7,948	5%	
Capacity building SI1- SI9	1,419	857	3,379	3,548	3,726	10,653	7%	
CRP Management	0	0	2,055	2,158	2,266	6,480	4%	
Consortium Board/FUND	0	0	1,028	1,079	1,133	3,240	2%	
CRP Total	**33,814**	**43,202**	**51,385**	**53,954**	**56,652**	**161,992**	**100%**	
Expenses by Region			**Optimized allocation**					
Asia & CWANA			9,341	9,808	10,299	29,448	18%	
E&S Africa			13,418	14,089	14,794	42,301	26%	
W&C Africa			5,752	6,040	6,342	18,133	11%	
Latin America & Caribbean			10,256	10,769	11,307	32,332	20%	
Globally implemented activities: SI8 & SI9			9,535	10,011	10,512	30,058	19%	
CRP Management			2,055	2,158	2,266	6,480	4%	
Consortium Board/FUND			1,028	1,079	1,133	3,240	2%	
Total			**51,385**	**53,954**	**56,652**	**161,992**	**100%**	
Expenses by Institution or Program			**Based on 2009-2010 proportions**					
CIMMYT	22,603	28,429	33,367	35,036	36,787	105,190	65%	
GCP	0	0	0	0	0	0	0%	
IITA	4,023	4,315	5,452	5,725	6,011	17,188	11%	
Partners	7,188	10,458	11,538	12,115	12,721	36,374	22%	
Consortium Board/FUND	0	0	1,028	1,079	1,133	3,240	2%	
Total	**33,814**	**43,202**	**51,385**	**53,954**	**56,652**	**161,992**	**100%**	
Expenses by Category			**Based on 2009-2010 proportions**					
Personnel Costs	9,816	12,112	14,102	14,807	15,548	44,457	27%	
Supplies and Services	8,523	9,162	11,091	11,646	12,228	34,965	22%	
Travel	1,589	2,173	2,359	2,477	2,601	7,437	5%	
Workshops/Conferences/Training	764	1,657	1,518	1,594	1,674	4,786	3%	
Collaborators	8,319	10,458	11,067	11,620	12,201	34,889	22%	
Depreciation and Capital Expenditures	347	2,218	1,609	1,689	1,774	5,072	3%	
Institutional Management	4,456	5,423	6,555	6,883	7,227	20,665	13%	
CRP Management	0	0	2,055	2,158	2,266	6,480	4%	
Consortium Board/FUND	0	0	1,028	1,079	1,133	3,240	2%	
Total	**33,815**	**43,202**	**51,385**	**53,954**	**56,652**	**161,992**	**100%**	
CRP-specific Management								
Global leadership and meetings	0	0	500	525	551	1,576	24%	
Regional leadership and meetings	0	0	500	525	551	1,576	24%	
MC & Advisory Board	0	0	130	137	143	410	6%	
CRP Knowledge Management	0	0	450	473	496	1,419	22%	
CRP Monitoring and Evaluation	0	0	475	499	524	1,498	23%	
Total	**0**	**0**	**2,055**	**2,158**	**2,266**	**6,479**	**100%**	

Table 7B. Income and expenses for Scenario 2 "CGIAR Baseline 5% + New Management"

Scenario 2 "CGIAR Baseline 5% + New Management"	2009	2010	2011	2012	2013	Total 2011-13	Percent 2011-2013	Comments
Income								
CGIAR Window 1-3: Research	9,434	10,424	10,945	11,493	12,067	34,506	20%	5% increase 2011-13
CGIAR Window 1-3: CRP Management	0	0	2,159	2,267	2,380	6,805	4%	All management
CGIAR Window 1-3: Consortium Board/FUND	0	0	1,079	1,133	1,190	3,403	2%	All management
Bilateral funding, secured	24,380	32,778	24,565	15,688	10,528	50,782	30%	
New bilateral funding (pipeline)	0	0	15,218	26,084	33,333	74,634	44%	
Total	**33,814**	**43,202**	**53,966**	**56,665**	**59,498**	**170,129**	**100%**	**71% of full funding**
Total CGIAR Window 1-3	9,434	10,424	14,183	14,893	15,637	44,713	26%	
Total Bilateral funding	24,380	32,778	39,783	41,772	43,861	125,416	74%	5% increase 2012-13
Proportion CGIAR Window 1-3	28%	24%	26%	26%	26%	26%		
Expenses by Strategic Initiative			**Optimized allocation**					
SI1 Socio-economics	2,239	4,332	6,290	6,604	6,935	19,829	12%	
SI2 Systems intensification	4,000	7,704	8,940	9,387	9,856	28,183	17%	
SI3 Yield gap	412	607	1,516	1,592	1,672	4,781	3%	
SI4 Stress environments	14,449	19,126	10,038	10,540	11,067	31,644	19%	
SI5 Double yield	2,556	3,343	6,110	6,415	6,736	19,261	11%	
SI6 Post harvest	1,422	1,790	3,563	3,742	3,929	11,234	7%	
SI7 Nutrition	2,088	1,733	709	744	781	2,234	1%	
SI8 Genetic diversity	2,470	2,303	7,366	7,734	8,121	23,220	14%	
SI9 Tools	2,758	1,407	2,648	2,780	2,919	8,348	5%	
Capacity building SI1- SI9	1,419	857	3,549	3,726	3,913	11,188	7%	
CRP Management	0	0	2,159	2,267	2,380	6,805	4%	
Consortium Board/FUND	0	0	1,079	1,133	1,190	3,403	2%	
CRP Total	**33,814**	**43,202**	**53,966**	**56,665**	**59,498**	**170,129**	**100%**	
Expenses by Region			**Optimized allocation**					
Asia & CWANA			9,810	10,301	10,816	30,928	18%	
E&S Africa			14,092	14,797	15,537	44,426	26%	
W&C Africa			6,041	6,343	6,660	19,044	11%	
Latin America & Caribbean			10,771	11,310	11,875	33,956	20%	
Globally implemented activities: SI8 & SI9			10,014	10,514	11,040	31,568	19%	
CRP Management			2,159	2,267	2,380	6,805	4%	
Consortium Board/FUND			1,079	1,133	1,190	3,403	2%	
Total			**53,966**	**56,665**	**59,498**	**170,129**	**100%**	
Expenses by Institution or Program			**Based on 2009-2010 proportions**					
CIMMYT	22,603	28,429	35,043	36,796	38,635	110,474	65%	
GCP	0	0	0	0	0	0	0%	
IITA	4,023	4,315	5,726	6,012	6,313	18,052	11%	
Partners	7,188	10,458	12,118	12,724	13,360	38,201	22%	
Consortium Board/FUND	0	0	1,079	1,133	1,190	3,403	2%	
Total	**33,814**	**43,202**	**53,966**	**56,665**	**59,498**	**170,129**	**100%**	
Expenses by Category			**Based on 2009-2010 proportions**					
Personnel Costs	9,816	12,112	14,810	15,551	16,329	46,690	27%	
Supplies and Services	8,523	9,162	11,648	12,231	12,842	36,722	22%	
Travel	1,589	2,173	2,478	2,602	2,732	7,811	5%	
Workshops/Conferences/Training	764	1,657	1,595	1,674	1,758	5,027	3%	
Collaborators	8,319	10,458	11,623	12,204	12,814	36,642	22%	
Depreciation and Capital Expenditures	347	2,218	1,690	1,774	1,863	5,327	3%	
Institutional Management	4,456	5,423	6,884	7,229	7,590	21,703	13%	
CRP Management	0	0	2,159	2,267	2,380	6,805	4%	
Consortium Board/FUND	0	0	1,079	1,133	1,190	3,403	2%	
Total	**33,815**	**43,202**	**53,966**	**56,665**	**59,498**	**170,129**	**100%**	
CRP-specific Management								
Global leadership and meetings	0	0	525	551	579	1,655	24%	
Regional leadership and meetings	0	0	525	551	579	1,655	24%	
MC & Advisory Board	0	0	140	147	154	441	6%	
CRP Knowledge Management	0	0	485	509	534	1,527	22%	
CRP Monitoring and Evaluation	0	0	485	509	534	1,527	22%	
Total	**0**	**0**	**2,159**	**2,267**	**2,380**	**6,806**	**100%**	

Expenses by Strategic Initiative: The optimal allocation of expenses by Strategic Initiative was assessed based on qualitative stakeholder feedback collected over the past three years. This assessment will be adjusted between 2011 and 2013 through ex-ante impact analysis (improving estimates provided in Table 2) and through systematic prioritization by stakeholders. The high level of bilateral funding to MAIZE makes optimal allocation of funds across Strategic Initiatives problematic, unless funds can be sourced that are very much aligned with the MAIZE Strategy or FUND members transform restricted, bilateral funding into CGIAR Window 1-3 funding. The more donors restrict their funding to particular projects, the greater will be the potential variation from the budgeted, optimal allocation of funds. This discrepancy originates mainly from somewhat different priority setting of partners and donors. Based on current insights, it would be desirable to re-allocate budgets from *SI 4 Stress tolerant maize for the poorest* to most other Strategic Initiatives for greatest impact across MAIZE. Investment in *SI 7 Nutritious maize* is shown to decrease between 2010 and 2011 because most of these activities are budgeted under *CRP4 Agriculture for improved nutrition and health*.

Expenses by Region: The optimal allocation of expenses by region is based on the regional importance of maize for maize farmers and poor maize consumers (FAOSTAT 2010; Table 8) and summarized by the management entities shown in Figure 10.

Expenses by Strategic Initiative and Region. Regional budget allocations to individual Strategic Initiatives will depend on the relative priority of each Strategic Initiative for a particular region, as determined through A. Ex-ante impact analysis and systematic stakeholder consultation and B. Available bilateral funding. Consortium funds will be used to address gaps between A and B and this will be assessed on an annual basis by the Management Committee.

Table 8. Regional importance of maize production and consumption

		Relevance of maize for various regions					
Description	Weight	Africa – E&S	Africa - W	Asia - East	Asia - S&SE	CWANA	LAC
Area	50%	20%	12%	9%	23%	3%	34%
Production		11%	6%	15%	22%	5%	41%
Poor < 1 USD		27%	36%	3%	15%	6%	13%
Poor < 2 USD		25%	26%	4%	23%	8%	13%
Maize kcal < 1 USD		53%	22%	1%	6%	1%	17%
Maize kcal < 2 USD	50%	49%	18%	1%	10%	3%	19%
Weight	100%	35%	15%	5%	16%	3%	26%

Notes: Asia - E: Assumption is that 75% of the area/poor is temperate, 25% subtropical/tropical

Expenses by institution or program are based on 2009-2010 averages. Budget allocations among CIMMYT, IITA, and partners in 2009 and 2010 were 66%, 11%, and 22%, respectively. The Generation Challenge Program contributes 2% of the available 2009 and 2010 budget of MAIZE, and all of that is allocated to Generation Challenge Program partners, indicating zero resources to the Generation Challenge Program from MAIZE, but contributing to partners' budgets. In 2010, partner allocations to MAIZE-equivalent activities were as follows:

- **Partners for globally-managed activities (8% of all partner funding):** Yunnan Academy of Agricultural Sciences in China, Kenya Agricultural Research Institute in Kenya, Syngenta Company, the University of Freiburg and the University of Hohenheim in Germany, and Virginia Tech University in the USA.
- **Regional or international partners for regionally-managed activities (31% of all partner funding):** Africa Agricultural Technology Foundation in Kenya, the Association for Strengthening Agricultural Research in Eastern and Central Africa, ICRISAT, IFPRI, K BioSciences, Monsanto, Murdoch University in Australia, Pioneer HiBred, Queensland Department of Employment, Economic Development and Innovation, Queensland University in Australia, and the University of Georgia.
- **National partners for regionally-managed activities (61% of all partner funding):** Members of NARS-led national maize working groups—including NARS, the private sector and CBOs/NGOs—in Angola, Bangladesh, Benin, Botswana, El Salvador, Ethiopia, Ghana, Honduras, India, Kenya, Lesotho, Malawi, Mali, Mexico, Mozambique, Nepal, Nicaragua, Nigeria, Peru, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe. Funding allocations are decided after peer review; subcontracts are based on prioritization and advice from regional steering committees.

Between 2011 and 2013, total partner funding is expected to increase. However, given that total funding to partners in MAIZE will likely exceed the total amount of funding provided by CGIAR Window 1-3, bilateral project contracts will remain a critical factor in determining detailed partner budgets. Partnership details will be included in the annual operational plans and reports of MAIZE, and decided through collaborative planning in sub-regional and global teams.

Expenses by category are based on 2009-2010 averages. Institutional management costs are 15% for CIMMYT and 20% for IITA, and averaged in proportion to each institution's budget.

Breakdown of MAIZE management costs. It is assumed that 2% of the overall budget for MAIZE is reassigned to the Consortium to cover Systems costs. In case this proportion changes, so will the budgets for Scenario 1 and 2. It is estimated that MAIZE will require 4% additional management investment that will not be covered by institutional overheads. The budget will cover the costs for global and regional leadership and meetings (assuming alignment of meetings with bilateral projects), costs by the Management Committee and Oversight Committee, knowledge management across MAIZE, and monitoring and evaluation beyond impact assessment done in *SI 1 Socioeconomics and policies for maize futures*. In general, management costs imply a very high level of direct costing of activities which leads to administrative inefficiencies but is desired by donors. If the management costs of any other CRP are above 4%, MAIZE reserves the right to increase its management costs to a CGIAR-wide agreed level which will affect budgets for Scenario 1 and 2.

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MAIZE Strategic Initiatives

Strategic Initiative 1. Socioeconomics and policies for maize futures: Technology targeting, institutional innovations, and markets for sustainable productivity growth and food security in maize

Value proposition

Enhance the client orientation and impacts on food security, poverty, and the environment of maize research for development interventions—increasing their effectiveness, efficiency, and inclusiveness in reaching disadvantaged farmers and consumers.

Estimated impact	
Benefits to scientists and partners	Better targeting of interventions to reach the poor; foresight to inform breeding; better policies for impact and price stabilization; valuation of traits; better priority setting; gender mainstreaming; better policies for sustainable and inclusive growth.
Benefit to the poor	More relevant and accessible maize innovations available to the poor. Earlier access to maize innovations. Higher smallholder income; cheaper food for consumers.
Benefit to the environment	Increased diversity and more sustainable intensification of maize-based systems along rainfed to irrigated continuum. Reduced pressure on marginal environments.
Others	Positive spillovers to non-maize R&D within national and global programs.

Justification

General background

Smallholder maize production in developing countries is stymied by technological, biophysical, and socioeconomic constraints. Future productivity growth to meet the growing demands for maize will require holistic approaches that address market, policy, and institutional constraints, near-term and longer-term food price development. Numerous socioeconomic factors impair smallholder farmer adoption of productivity-enhancing technologies, including limited access to information, seeds, other inputs, equipment, services, or markets for selling surplus produce (Pingali 2001; Morris et al. 2003; Langyintuo et al. 2010). To be effective, an agricultural research program must address the needs of heterogeneous groups of farmers, consumers, and marketing agents along the production-to-consumption value chain, and overcome obstacles to national agricultural policy objectives. At the international level, improved understanding of food price developments are needed in support of domestic and international policy dialogue and coordination, also market-based risk management tools for vulnerable producers and governments to improve their capacity to manage and mitigate food price volatility. Socioeconomics research will play an important role in meeting these objectives and in anticipating social, political, and economic trends that shape local and global food systems.

Stability of production and policies for price stabilization are critical for protecting the welfare of poor consumers as well as global food security. Developing country input and output markets for maize and other staples suffer, however, from high levels of imperfections—mainly induced by policy failures, poor access to useful information, and lack of complementary investments in public goods and market institutions (de Janvry et al. 1991; Jayne et al. 2006; Gregory and Bumb 2006; Langyintuo et al. 2010). Increasing production is difficult to sustain under low and inelastic demand, which often causes prices to tumble when local markets fail to absorb surplus production (Several past studies (de Janvry et al. 1991; Vitale and Sanders

2005; Jayne et al. 2006). Sustained technology adoption and productivity growth for maize in the developing regions will require complementary research to identify institutional innovations and policies that enhance market efficiency and distributional outcomes. Institutional supports are also needed to mitigate downside price risks (absorbing excess production in cases of low and inelastic demand) and to protect both global food security and poor consumers' welfare by preventing food price surges.

This strategic initiative (SI 1) will work closely with CRP2 on 'Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor' and other SIs in MAIZE to enhance the relevance and overall impact of maize-specific interventions on the poor. Particularly, this involves understanding systemic constraints and determining gender-related technology choices and preferences, identifying target domains, and fostering institutional innovations and policies that enhance the performance of input and output markets for maize, locally and globally. SI 1 will also produce forward-looking and policy-relevant studies on alternative futures for maize, including analysis of demand for food, feed, and other uses, supply conditions, and price trends. The strategic research under this SI will produce institutional and policy innovations adapted to specific socioeconomic environments, supporting deployment and adoption of maize technologies.

Why international agricultural research?
National research programs often lack the social science capacity or political influence to address these challenges alone, and many policy, market, and institutional constraints are regional or global in nature. National and regional policy research institutes, universities, the private sector, and relevant farmer organizations must join with international centers and advanced research institutes, particularly to focus on the needs of low- and middle-income countries.

Progressing the initiative
The overall objective of this initiative is to build on past socioeconomics and policy research on maize and provide a social science context for MAIZE. Social scientists will work closely with breeders and agronomists to complement and enhance the relevance and effectiveness of the work proposed under the other initiatives, developing innovations that better target the needs of resource-poor farmers. Geospatial analysis and ex ante impact studies will increase researchers' understanding of maize system constraints. This SI provides the institutional base for strategic socioeconomics research on maize systems while ensuring coherent collaborative research with the other maize SIs—aiming to increase adoption and ultimately impact. The SI will thus focus on MAIZE target countries/regions, but will generate research outputs such as knowledge, data, tools, institutional innovations, and policy options, actively enabling their use by other SIs through scenario analysis and participatory approaches, to ensure that MAIZE outputs (germplasm, agronomy, and training) meet the needs of farmers and key stakeholders. At the gobal level, the SI will work closely with CRP2 on 'Policies, institutions, and markets to strengthen assets and agricultural incomes for the poor' and evolving socio-economic and GIS databases (such as from FAO, or from institutions engaged in remote sensing and climate assessemnt) to use existing and new data and apply various quantitative and qualitative analytical approaches to generate food price relevant information and market-oriented interventions that stabilize food prices.

Progress to date and the lessons learned

- Adoption of improved maize varieties has generally been high in high-potential areas with good access to markets for supply of seed, other inputs (e.g. fertilizer) and credit for small-scale producers. Resource-poor farmers (including women) in the same areas and farmers in drought-prone marginal regions are affected by high risks and limited access to markets, factors that reduce incentives to adopt new technologies (Kaliba et al. 2000; Thurtle et al. 2003; Morris et al. 2003).

- Targeting resource-poor farmers in both low- and high-potential areas would require integrated technological and institutional innovations that increase access to locally adapted maize germplasm and marketing services—to enhance expected returns, hedge production risks induced by climatic variability, and improve market opportunities for surplus produce and essential inputs (Shiferaw et al. 2008; Barrett 2008). Understanding of gender-specific roles and constraints in maize production will facilitate the delivery of appropriate varieties for poor farmers (Quisumbing and Pandolfelli 2009).
- Despite the increasing role of multinationals and the private sector in maize seed systems, many poor farmers rely on local seed companies that supply open-pollinated varieties. Participation in the seed sector is limited by policy and credit constraints. New approaches are required to facilitate the transfer of genetic materials between the public and private sectors and to accelerate regional spillovers across suitable agro-ecologies through policy harmonization and market development (Morris et al. 2003; Langyintuo et al. 2010).
- Development of rural financial markets helps enhance farmers' access to inputs and improve traders' capacity to absorb surplus production. Market institutions such as warehouse receipt systems can inject needed liquidity into grain-marketing systems, absorbing surplus production in good years (Jayne et al. 2006). Farmer organizations and collective action institutions can also improve the economies of scale and farmers' access to both input and output markets (Barrett 2008; Shiferaw and Muricho 2009).
- Evidence-based research and policy making in maize-based farming systems need to be informed by an understanding of the socioeconomic and biophysical drivers of change, including poverty traps and development pathways in different regions.
- There is need for better analysis of near- and medium-term outlooks for maize under different scenarios (changing patterns of demand for alternative uses, effect of climate change, and effects on supply, prices, demand, trade, etc.), implications for competitiveness (Pingali et al. 2001) and global price risk management.

Researchable issues

- *Support for technological innovation and targeting the poor in priority regions and farming systems* This will include characterization of target groups, spatial modeling and systems analysis; ex ante impact assessment and priority setting for stress-tolerant and biofortified maize, post-harvest loss, and conservation agriculture; and ex post analysis of the adoption and impacts of maize technologies. This will enable social scientists to work closely with other scientists and will be relevant across SIs 2–9.
- *Developing institutional innovations to improve small-scale farmers' access to seed and other inputs and services* This will include in-depth characterization and constraint analysis of seed supply and input systems, followed by strategies to enhance public and private delivery of technologies, inputs, and services. It will also involve models for providing and financing inputs, information, and advisory services; and policy options and regulatory frameworks to support maize input systems. (Links with SIs 2–7.)
- *Chronic challenges to demand, local product markets, and more equitable value chains, including ways to reduce post-harvest loss and foster food safety and health* Maize is often grown in areas where infrastructure is poor and markets are thin and poorly integrated. Poor grain quality, poor storage and contamination, unreliable supply and high costs reduce market demand, while poor integration and imperfect information lead to high market risks and price volatility. Pest damage and mycotoxin contamination increase economic losses and cause health hazards. This research involves the design, testing, and development of institutional innovations, models and policy options to improve maize market linkages and their performance—thus benefitting resource-poor producers

and consumers and enhancing global food security. (Links with SIs 2 and 6, also Thematic Areas TA2 on value chains and TA4 on nutrition.)

- *The underlying socioeconomic dynamics and drivers of change that affect maize farming systems* Maize production occurs within complex and dynamic farming systems; identifying opportunities and challenges requires a solid micro-level understanding of the evolving role of maize within diverse livelihood portfolios. Snapshot studies are of limited relevance unless they can be positioned in a dynamic context to capture the drivers of change and technological innovation in representative farming systems. The micro studies will generate and use panel data from selected representative farming systems to analyze crop productivity and resource-use patterns, diagnosis and characterization of poverty traps/dynamics, gender differentiation, and development pathways in representative maize systems.
- In collaboration with CRP2, maize-specific information and modeling approaches need to be rapidly enhanced to (i) arrive at improved analyses of near- and medium-term global and regional analysis of maize food price developments and (ii) develop effective, market-based risk management tools for vulnerable producers and governments to improve their capacity to manage and mitigate food price volatility.
- *The challenge of climate change in maize farming systems.* Strategic knowledge on vulnerabilities, potential impacts, and adaptation options and strategies for maize farmers; policy options and instruments that enhance adaptation to, or mitigation of, climate change and thus protect livelihoods and maize production environments. This will provide the economic analysis to help articulate the value proposition for SI 4 as it responds to abiotic/biotic stresses associated with climate change (links with CRP7 on Climate Change and Agriculture.)

Outputs

1. Knowledge, tools, and methods for better targeting of R&D interventions and to achieve greater impacts in maize-based farming systems.
    - A geo-referenced database on maize yield constraints in a range of farming systems, for technology targeting and policy development relating to smallholder precision agriculture.
    - Ex ante evaluation and benefit estimation of drought tolerant maize, post harvest resistant maize, N use efficient maize, nutritionally enhanced maize, and conservation agriculture (CA) options.
    - Participatory approaches for farmer variety selection and local adaptation of technologies, including experiments to evaluate adoption of storage methods and sustainable CA systems.
    - Methods for monitoring and measuring progress towards primary (yield, area, production, income, risk) and second-order impacts (poverty, gender, hunger, ecosystem health).
    - Knowledge about the drivers of technology adoption, and databases on the spatial and temporal diffusion of improved varieties, hybrids, GM maize (in the long run) and conservation agriculture.
    - Gender-differentiated knowledge on the impacts of maize interventions on poverty, livelihoods, and system sustainability.
    - Capacity for technology targeting, up-scaling, and impact analysis.

2. Institutional innovations for improving farmers' cost-effective and timely access to maize technologies, input markets, and services.
    - Diagnosis of rights of access and use of productive resources (land, water, labor, seed) and how this would influence men and women farmers' investments in new technology and conservation agriculture.

- Knowledge of the structure and function of seed systems and complementary input systems in a changing global environment.
- Effective scaling out approaches to reach millions of poor and malnourished children in maize-based farming systems.
- Strategies for enhancing the different but complementary roles of the public and private sectors in delivering technologies and inputs to smallholder farmers.
- Gender equitable and pro-poor institutional innovations to strengthen seed systems and for the cost-effective and timely delivery of fertilizer, information, credit, and other services.
- Alternative frameworks for regulating seed and grain, including GM and bio-fortified maize, and policies that enhance equitable and accelerated access to seed and other inputs.
- Capacity for analysis of seed systems and input value chains.

3. More efficient markets and value chains that enhance market access and competitiveness, stabilize prices, and benefit farmers and poor consumers locally.
    - Knowledge on the demand for alternative uses of maize and the degree of differentiation in markets.
    - Key traits preferred by actors (including quality) in the maize value chains identified to enhance value chain integration of small producers and to guide breeding programs.
    - Knowledge and information on the economic importance of post-harvest losses, nutritional impacts of contaminated maize, and trade-offs faced by the poor.
    - Cost-effective innovations that enhance food quality, improve health and nutrition, and reduce maize grain losses and health risks.
    - Policy options and institutional innovations that reduce transaction costs, improve market access, stabilize food prices, and enhance the competitiveness of agro-enterprises.
    - Capacity for analysis of maize markets and improved utilization.

4. In collaboration with CRP2, knowledge on socioeconomic dynamics and drivers of agrarian change in maize farming systems.
    - Strategic knowledge on the regional and global situation and future outlooks for maize and investment opportunities to ensure regional and global food security.
    - Pioneer methods that iteratively improve the maize market outlook and forecasts at both national and international levels and link them with energy markets, policy monitoring, price transmission from world to domestic markets and food security assessments.
    - Explore the relations between biofuel and food production, the resilience of agriculture to price increase and volatility, and the sustainability of agriculture production.
    - Provide guidance to policy makers that influence domestic, regional and international responses to food security threats.
    - Disseminate market outlook information products to the domestic agricultural sector.

5. Knowledge on climate change vulnerability and options that enhance adaptation / mitigation in maize systems.
    - Mapping and characterization of climate-related risk; a survey of current formal and informal risk management strategies and existing policy approaches to manage food crises and price volatility for maize as a major food staple.
    - Diagnosis of production variability and risk of crop failure, vulnerabilities of communities and maize farming systems under current climatic variability and progressive climate change.

- Knowledge and information on the coping and adaptation strategies of farmers and the poor to heat, drought, land degradation, and water scarcity in maize production systems.
- Economically efficient, socially acceptable, and viable options to address current climatic variability and future climate change in maize production systems.
- Knowledge and analysis of climate-change-related economic incentives and benefits to farmers from adoption of conservation agriculture.
- Policy options and instruments for enhancing adaptation to and mitigation of climate change to protect livelihoods and sustainability of maize production environments.
- Capacity for analysis of maize futures and climate policies**.**

Research and development partners
CIMMYT, IITA, IFPRI (Outputs 4,5), Michigan State University (Outputs 2,3), Cornell University (Outputs 1,3,4) , UMB-Norway (Outputs 1,2,4,5), University of Gottingen (Outputs 1,2), Stanford University (Output 4), regional and global policy research institutes, national research and extension systems and universities in over 50 maize growing countries of Africa, Asia and Latin America (Outputs 1–5).

Sub-regional organizations: ASARECA, COMESA, SADC, ECOWAS, FARA, APPARI, etc. (Outputs 1–5); private and public sector value-chain participants (Outputs 2,3); NGOs, regulatory agencies, and governments (Outputs 1, 2).

Outcomes
- GIS maps and targeting tools used by a wider array of project scientists and partners.
- Better priority setting by scientists and partners.
- Adoption of institutional innovations for scaling out to improve delivery of inputs and services to farmers.
- Adoption of market innovations in maize value chains.
- Enhanced evidence-based decision-making by farmers.
- Adoption of market-oriented policy options for enhancing food price stability, adaptation and reducing vulnerability.
- Better information and policies for adaptation to climate change.
- Increased maize production from adoption of innovations.
- Better prices to producers and consumers from increased supply and pro-poor policies.

Key milestones
2011: Ex-ante economic/geospatial analysis of R&D opportunities in sub-Saharan Africa, South Asia, and Central America. Household typologies developed for targeting innovations in at least five farming systems with the greatest number of interventions (Figure 5). Develop and test tools and instruments for household, market, and farming system surveys. Scoping study on seed and input supply systems and output value chains for maize.
2012: Analysis of output markets and alternative uses of maize in Africa, South Asia, and Central America. Identify at least five farming systems and hubs to monitor socioeconomic dynamics. Analysis of vulnerabilities to climate change and existing coping mechanisms in two regions.
2013: Designing and testing of alternative institutional innovations for delivering technologies and inputs. Report on effective scaling-out approaches to reach poor and malnourished children. Analyze market and value chain survey data and synthesize lessons for policy. Design and test alternative options to reduce transaction costs and stabilize maize prices. Develop policy options for enhancing climate adaptation. Publications on global and regional maize futures.

2014: Analysis of policy options and support systems for enhancing farmer access to technologies. Analysis of coordination failures and policy issues in input and output markets. Value chain maps, distribution of transaction costs and margins. Analysis of varietal and quality preferences and end-users' desired traits. Publications, workshops, and conferences to communicate results.

2015: A publication on poverty dynamics, intensification and resource use, and drivers of change. A research report on institutional innovations to improve seed systems and enhance technology adoption by the poor. A report on institutional innovations to improve maize markets and access by small producers. Policy options and strategies for reducing production and market risks. Policy recommendations on the role of the public and private sector in price stabilization.

2016: Data and improved methods for technology targeting, up-scaling and evaluating impacts. Analysis of the spatial and temporal flows of technologies and the key drivers of adoption. Economic and social impacts (gender, social exclusion, etc.) of maize interventions. Publications and policy briefs. Synthesis of knowledge gaps and research needs for future research.

What's new in this initiative?

- Mobilization of international collaboration, data and now-how to respond to the rapidly changing food price situation.
- Integration of socioeconomic analysis with biophysical research priority setting, with a renewed focus on participatory approaches and ex-ante analysis to determine outcomes and impacts of proposed interventions across multiple SIs. Application of a new generation of partial (multi-market models, economic Surplus, IMPACT model) and general equilibrium approaches (CGEs) for ex-ante analysis of future outcomes, market prices, supply and demand projections, and understanding impacts of emerging drivers (climate change, income growth, urbanization, derived demand for maize as feed and other uses).
- Explicit focus on gender effects with emphasis on the changing roles of men and women in maize-based agriculture and strategies for improving the participation of women in technology development and equitable access to information, markets and other services.
- Increased interest in complex institutional innovations that improve access to information, technologies, and markets, as well as facilitating adaptation to and mitigation of climate change.
- Strategic systems analysis at the regional or farming systems levels by establishing panel data on resource use and productivity, income sources, poverty, varietal choice, and markets for anticipating change and defining development pathways.
- Use of recent advances in geospatial analysis and wealth ranking tools to target the resource-poor and specific biophysical and socioeconomic maize production constraints.
- Novel tools for market and value chain analysis to understand distribution of transaction costs, effect of grain quality on prices, storage and processing, market participation patterns, correlations between seed and output markets, and efficient strategies for linking farmers with markets.
- Improved understanding of ex-post impacts of research interventions on poverty, gender, and environmental outcomes, using new quantitative and qualitative tools and methods for integrated economic, social, and environmental impact assessment.

Targets and impact estimates

The targets are poor maize consumers and maize-based farming systems in low-income and low-middle income countries of eastern, southern, western and Central Africa; South and Southeast Asia, East Asia, and Latin America. There is a particular focus on the high-intervention areas indicated in Figure 5.

The major clients for the research products will be policy makers and the breeders and agronomists working in other SIs, also other scientists, policy analysts, governments, NGOs, and the private sector. While food price-oriented analyses will have an immediate impact through policy uptake, farmer-focused partnerships will progressively translate outputs into higher-level social outcomes and development goals—increased production, food security, marketed surplus, increased incomes, along with inclusive growth and gender equity and improved agro-ecosystem health. The SI will enhance MAIZE's client orientation and impact. The diffusion of innovations and desired development impacts will be confirmed through rigorous ex-post impact evaluations.

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Strategic Initiative 2. Sustainable intensification and income opportunities for the poor living in maize-based systems

Value proposition
Reduce poverty and hunger through integrated and scalable innovations that improve market access and increase the productivity, sustainability, and resilience of maize-based farming systems, reaching 25 million people by 2020 and 75 million people by 2030, and lifting at least 10 million out of extreme poverty within the first 10 years.

Estimated impact	2020	2030
Production increase	0.8 million tons	3.9 million tons
Income increase	USD 270 million	USD 1,350 million
Benefit to the poor in the maize-based systems	The target area includes 315 million poor and nearly 22% (35 million) of all stunted children worldwide .	
Benefit to the environment	Increased soil productivity, reduced soil erosion and flash flooding, increased carbon sequestration and reduced fuel use for tillage and pumping.	
Others benefits	Increased resilience from diversified income and reduced downside risk; higher income from better value chains; reduced drudgery for women and increased schooling for children.	

Justification
General background
Among the 15 rainfed farming systems worldwide with the greatest number of poor and malnourished children, six feature maize as the predominant crop (Hyman et al. 2008). Declining per capita productivity and inadequate investments in sustainable practices have locked millions of people into extreme poverty and a downward spiral, worsening deprivation and vulnerability. Maize production is the pillar for these communities. But reducing hunger, malnutrition, poverty, and environmental degradation requires integrated and complementary solutions (to address multiple bottlenecks along the value chain and create multiplier effects) together with the best available maize technologies.

Drawing on available technologies and institutional innovations from MAIZE and other commodity research programs, inside or outside the CGIAR, this SI aims to identify and leverage opportunities for poverty reduction through productivity enhancement, income growth, and sustainable intensification. This will ensure that those from vulnerable and poor households—especially women—benefit from new technologies, information, and integration into markets and value chains. The science will involve adapting technologies and institutional innovations to local conditions, linking farmers with markets and better policies that enable inclusive growth.

Why international agricultural research?
This Strategic Initiative will focus on the six most important maize-based systems worldwide (Hyman et al. 2008) that cut across borders—where inter-disciplinary and inter-institutional approaches can trigger cross-institutional learning and scalable solutions to reach potentially 315 million people and 22% of all malnourished children. The research will be implemented and championed by national and local collaborators. International centers will study and help develop locally adapted systems and strengthen national capacity, ensuring a well-designed research-for-impact agenda focused on specific constraints

and opportunities. Efforts will draw on the best CGIAR science for large-scale and sustainable impacts on poverty, vulnerability, and ecosystem degradation.

Lessons from past research

The overall strategy and focus of the Strategic Initiative has evolved from CIMMYT's and IITA's long histories (over 30 years) of farming systems research for poverty reduction, food security and increasing sustainability. Some of the principal lessons that have emerged from the extensive farming systems and poverty analysis work are:

1. Integrated interventions that address multiple constraints to farmer adoption of productivity enhancing technology and investments in sustainable practices along the production-to-consumption chain offer a promising development pathway for lifting large numbers of people out of poverty (Barrett et al. 2002; Shiferaw et al. 2009).
2. Integrated interventions build on specific successful innovations for improving productivity of selected commodities (drought-tolerant maize and improved varieties of other crops within the maize systems) but also exploit the positive interactions among the different technology components (rotation systems and intercropping for ensuring dietary and income diversification or strengthening crop–livestock linkages).
3. Men and women farmers (including elders and young adults) may have differing roles in agricultural systems, and face varying constraints and preferences for different technologies. Technology design and adaptation need to reflect these gender-specific roles and constraints and develop pro-poor technological and institutional innovations through participatory approaches that meet diverse farmer needs and unlock the process of local innovation (Quisumbing and Pandolfelli 2009; Meinzen-Dick et al. 2010) .
4. A better targeting approach for scaling up/out innovations needs to take into account differences in biophysical and socioeconomic conditions. Adaptation of complex technologies to farmer circumstances will need to start in selected representative areas that capture these differences for effective learning and scaling up/out, rather than being spread out over a wide geographical area. At the same time the role of the farmer-innovator in initiating change in farming communities is crucial to success.
5. Sustainable conservation agriculture (CA) systems result from the adaptation of techniques and technologies that apply the three basic principles—minimum soil disturbance, surface residue cover, and crop rotation—to particular farming systems. Disregard for this fundamental point has led to negative experiences with CA-based technologies in many places, where imported "CA packages" applied without proper adaptation have failed (Giller et al. 2009).
6. There is a wealth of scientific evidence that tillage-based agriculture in tropical and subtropical environments leads to soil structural degradation, in turn resulting in decreased soil fertility, increased water run-off and erosion, increased frequency and severity of droughts, and ultimately in land abandonment. There is an urgent need for implementing sustainable practices that maintain and increase farm-level productivity and give small farmers access to the CA-based approaches that have restored and increased soil productivity in many developed regions. An effective approach is to create economic incentives for adoption by building on high-return components that raise productivity, create income opportunities, reduce vulnerability, and improve livelihoods. Such components promote investments in more sustainable practices by resource-poor farmers (Barrett et al. 2002; Shiferaw et al. 2009).
7. Smallholder farmers in rainfed areas know about the benefits of fertilizer and often use it on high-value cash crops. Use of fertilizer on staple crops such as maize is often low because of climate and price risks associated with fertilizer application. Improved risk management (whether through

stress-tolerant germplasm, better agronomic practices, storage facilities or insurance schemes) is crucial for farmers to increase their investments in food crops.

8. The complexity of farming systems and farmer decision-making has hindered the identification of improved systems, especially in regions of low crop productivity and relatively high climatic or price risk. However, research and participatory technology development show that these obstacles can be overcome when economically attractive options exist for smallholder farmers to adopt technologies that progressively enhance system sustainability and resilience. Also, under such circumstances sole reliance on a linear model of technology development and knowledge flow is unsuccessful and needs to be replaced by multi-agent innovation systems focused on achieving change with a clear farmer-relevant performance goal. Finally, access to information and knowledge development in farming communities is the key to the adaptation of complex technological change.
9. Policy and institutional innovations in the delivery of key productivity-enhancing technologies (improved seeds) and inputs (fertilizer), equipment (seed drills, irrigation, conservation tillage) and access to credit and finance as well as enhanced linkages with output markets for income generation are critical in overcoming market imperfections that limit farmer adoption of new technology. With effective capacity-building in agribusiness and marketing skills, producer cooperatives, farmer associations, marketing groups, self-help groups and other local collective action, institutions can play an important role in connecting resource-poor farmers with input and output markets (Barrett et al. 2002; Shiferaw et al. 2009).

Implementation of the Strategic Initiative

Expertise and innovations from different CGIAR centers will be integrated into options that allow sustainable intensification and productivity growth to improve livelihoods and food security and reduce vulnerability and extreme poverty in maize-based systems. Components of these systems will include drought-tolerant and better-yielding varieties of maize and legumes, multi-purpose tree crops, and efficient water and nutrient management practices that are affordable and can be scaled up to reach large numbers in poor and vulnerable populations. This will be supported by innovations in value-chain linkages and better policies that help the poor benefit from existing market opportunities to access seeds, fertilizer, and other inputs and services, as well as to sell their surplus produce for added income. On-farm participatory research and bio-economic modeling methods (for different household typologies facing different constraints) will be used to identify optimal enterprise combinations and technologies that raise productivity, increase profitability and incomes, and reduce risks while enhancing the sustainability of maize-based systems. The integrated technological and institutional innovations will progressively aim to implement the principles of conservation agriculture and to foster adoption of sustainable solutions at the farm and landscape level.

"Hubs[8]" will be established in representative agro-ecologies in the principal maize-based systems. Local innovation systems will be catalyzed, incorporating national research and extension systems (NARS[9]), development agencies, the private sector, international centers and advanced research institutes. Within the hub an efficient and coordinated research program focused on attaining more productive and sustainable systems on the farms of innovative smallholder farmers in several target communities

[8] Other institutions and entities also use the term "hubs" for activities focused in a geographic region. However, objectives are often very different, and so it is impossible to assume that solely because of the name there is a benefit to having hubs with different objectives in the same place. However, hub locations will be defined with partners in the regions in order to achieve maximum representativeness and impact.

[9] Here writ broadly, encompassing public sector research and extension systems, universities, NGOs, CBOs and any other institution involved in agricultural research and extension at the national level. The innovation system will draw on the comparative advantages, technical networks and opportunities of all potential participants in the system.

will be established. Generally this will include farmer-managed, multi-year technology evaluations and validation plots comparing farmers' common practice with two or more "best-bet" options. Technology options will be based on ex ante analysis (linked to SI 1); they will also be dynamic with the capacity for modification over time to incorporate new options for system optimization and intensification based on farmer observations and ongoing research. The validation plots will be supported by (i) on-farm research to respond to problems and opportunities observed in the farmer trials and experiments, (ii) researcher-managed trials on technological components, (iii) participatory farmer-led evaluation and modification, and (iv) long-term trials to evaluate and understand the effects on system sustainability parameters such as soil quality, weed, pest and disease dynamics and greenhouse gas (GHG) emissions and carbon sequestration (the latter feeds into CRP7 on Climate Change and Food Security.

Socioeconomic studies and analysis of farmer circumstances and the value chains surrounding the principal enterprises representative of the farming system will support the local innovation system (with link to SI 1). Hubs will also serve as benchmark sites for monitoring socioeconomic dynamics and drivers of change, including the effects of land tenure and land policy. Promising innovations from the hubs will be tested initially through participatory approaches in selected satellite areas before scaling up to the wider target region. Impact assessment of the systems within the region of the hubs, together with extrapolation of the potential benefits through system simulation models, will support policy dialogue and the scaling up/scaling out of the methodologies and technologies.

The hubs constitute focal points for applying technologies, institutional innovations, and methodologies developed in other SIs and CGIAR Research Programs. Their evaluation within local innovation systems, focused on the participatory development of more productive, socially acceptable, and sustainable production systems, together with the feedback to technology generators, will be an important component of MAIZE. There are strong links between SI 2 and many of the other MAIZE SIs, as well as strong collaboration in the hubs between biophysical and social scientists. Finally, the hubs will serve as "nuclei" from which locally adapted technology and innovations will spread to adjoining target areas through the coordinated up/out-scaling efforts of development partners. The hubs will serve as bases for biophysical and socioeconomic training for researchers, change agents and development agencies. Those trained will come from national agencies and other regions with similar conditions and constraints. This training will serve as a major component to scale up/out technologies and methodologies, as well as a key part of international centers' exit strategy.

Undoubtedly technical problems, as well as opportunities for system enhancement, will become evident in validation plots in farmers' fields. These will provide the agenda for the applied research supported by the innovation system. Options for system improvement will be investigated under representative conditions using different and appropriate levels of researcher management and farmer participation, and new options incorporated into the farmer-managed validation plots where they will be evaluated by gender-differentiated groups in the community. As part of this process, knowledge development on the processes of soil degradation and rehabilitation, crop and system productivity in the farming community, and the innovation system will guide multiple learning activities.

Within the context of the smallholder farmer, the focus of SI 2 and of MAIZE in general will be to increase the productivity and reduce the risks associated with climate and market variability rather than increase the area of maize grown by farm families. This will allow farm households to attain food security and diversify their incomes, especially when associated with labor-saving technologies, to meet basic food needs from a smaller area of a well-managed crop, while allocating some land and labor for high-value enterprises and/or embarking on other livelihood options.

Researchable issues

- Effective approaches for targeting the poor and vulnerable groups and scaling up promising innovations (including delivery of seed and equipment) to wider target regions, for rapid gains in alleviating poverty.
- Context-specific knowledge on drivers of adoption of improved technologies (new varieties, CA systems, soil fertility enhancing opportunities) disaggregated by wealth and gender, tradeoffs (economic vs. sustainability) and on- and off-site impacts of interventions on poverty and gender equity in maize-based systems.
- Integrated interventions that raise productivity and incomes to benefit vulnerable groups (resource-poor men, women, senior citizens, and young adults) and cost-benefit-risk analysis of various options to scale-up across space and time, using best available GIS data and crop and socioeconomic models.
- Under-utilized market opportunities and critical intervention points in the value chains of the principal enterprises in maize-based systems.
- Economic (cost saving, yield, income diversification, and risk) and sustainability tradeoffs associated with investments in new technologies and sustainable crop management practices.
- Research-to-farmer pathways and technology and input delivery systems that improve timely availability and uptake of seeds and more sustainable crop management practices by the poor.
- Pathways to achieving adoption of sustainable systems based on the principles of CA in smallholder farming communities managing maize-based systems.
- The effects of CA systems and system options on weed, pest, and disease dynamics.
- Optimum levels of crop residues to reduce evaporation and build soil organic matter content and soil biological activity, while meeting other needs such as providing livestock feed. Can distinct maize-based systems support more diversification/intensification, including higher-value forages?
- Approaches optimized to use and combine sustainable crop management practices (CA-based technologies, legume rotations, fertilizer trees) from CGIAR sources, by assessing and analyzing risks, economic returns, and impacts on sustainability.
- Factors that underpin the benefits of crop rotations in CA-based systems, enhance biological nitrogen fixation and increase soil phosphorus availability.
- Poverty reduction, social (gender, equity, social exclusion effects) and sustainability gains resulting from the diffusion of promising integrated and complementary innovations.

Outputs

1. Geo-spatial information on poverty and socioeconomic profiles in target environments; knowledge on livelihood strategies and sources of income growth in different maize-based systems (links with SI 1 and other SIs).
2. Pro-poor, risk reducing, and income increasing technologies for regions with maize-based systems that lift large numbers of poor people out of poverty including:
    - Alternative approaches for farmers' land, labor, and financial resource allocation to crops (maize, legumes, trees, cash crops) and livestock that increase incomes and reduce risks (links to SI 1 and other CRPs).
    - Access to the newest stress-tolerant crop varieties, both from MAIZE (link to SI 4) and other CG efforts, by linking local seed companies that are producing these varieties to communities with an effective demand.
    - Conservation agriculture-based practices, including affordable and adapted equipment, that are implementable on smallholders' farms and increase the sustainability and resilience of farming systems (link to CRP7 on Climate Change and Agriculture).

3. Decision guides linked to weather forecasting services to efficiently supply farmers with timely, in-season information on optimal fertilizer management strategies (links with SIs 1 and 3).
4. Information and decision guides for maximizing systems productivity in different environments and under variable conditions of risk and value of produce and crop residues (links with SI 3).
5. Tools and methods based on economic and systems modeling to increase incomes, reduce downside risks, and foster diversification in maize-based systems (links with SI 1).
6. Better use of underutilized markets and stronger farmer-market linkages for income growth and adoption of sustainable conservation agriculture-based systems (links with SI 1).
7. Innovative systems, via information and communications technology (ICT)-based tools, to empower the poor with timely market information and agronomic recommendations, in pilot areas (links with SIs 1 and 3).
8. Through linkages with CRP5 on Soil and Water, gather field data showing the potential district, watershed, and regional effects of improved maize-based systems.

Research and development partners

National research systems of countries in the target regions will be the main research partners, supported by CIMMYT (maize) and IITA (maize, root crops, soybeans), ICRAF (trees-CA), ICRISAT (pigeonpeas, groundnut), ILRI (maize-fodder, multipurpose legumes), CIAT (beans), farmer groups, private sector (ICT and other service providers), advanced research institutes (Cornell University, Stanford University, Oklahoma State University, UMB—Norway, CSIRO—Australia, University of Florida, APSRU—Australia, University of Washington—USA, CIRAD—France, EMBRAPA—Brazil and others).

National agricultural extension systems, national and international NGOs (including CARE International, CARITAS, CRS, Concern Universal, Save the Children, World Vision etc.), FAO, the African Conservation Tillage Network (ACT), ASOSID, Mexico, the private sector (seed companies, machinery manufacturers, input suppliers, credit agencies, regulatory agencies, seed traders associations, grain traders, etc.) and farmer organizations will be candidates for participation in local innovation systems, depending on their geographical presence, and will also be major development partners of the SI.

Outcomes

- Development partners, policy makers, researchers, and change agents are able to identify viable options for rapid and sustainable poverty reduction in maize-based systems.
- Value-chain actors and service providers benefit from market innovations and take steps to link the poor into markets to access inputs and equipment and increase incomes.
- Poor farmers and women benefit from increased productivity, reduced risks, and improved food security, while reducing or reversing negative impacts on soils and the environment.
- Policymakers' focus on poverty is renewed; researchers/change agents are better equipped to catalyze and lead multi-agent innovation systems, as well as to facilitate information/knowledge flows.
- Reduced soil erosion, siltation, and flash-flooding downstream from agricultural areas.
- Reduced greenhouse gas emissions, especially as a result of reduced fuel use in agriculture, and increased carbon sequestration in agricultural soils, thereby mitigating climate change.
- Increased biological control of pests accompanied by a reduction in pesticide use.

Key milestones

2011: Maize-based system and poverty profiles characterized and constraints mapped using existing information and community surveys.

2011: Promising technologies identified and links established with other institutions with crucial research capacity for complementary crops, trees, or livestock, resulting in an inter-disciplinary, inter-institutional research for development team.

2012: Representative benchmark sites for specific agro-ecologies within maize farming system identified and established (6–10 per farming system). Farmer-participatory research trials implemented with a distinct number of integrated technology and innovation options—including improved varieties, conservation agriculture practices, crop rotations, crop diversification, and other variations of farmer resource allocation.

2012: Baseline surveys started in communities, households, and markets around research hubs, and in selected areas where no interventions are taking place.

2013: Baseline data analyzed and limitations to system productivity, including value chains of the principal enterprises, documented for each of the target productions systems in the hubs.

2013: Ex-ante analysis of economic profitability, poverty reduction, and sustainability gains from tested and potential interventions assessed.

2014: Initial results from integrated technologies and CA-based innovation systems tested in consultation with farmers (2011–13), and opportunities for improvement, intensification, and diversification incorporated into participatory on-farm research programs. Outside development partners exposed to ongoing research, and scale-out opportunities discussed.

2014: Crop/soil simulation models validated across several hubs. Optimal enterprise mixes for sustainable intensification, risk reduction, and inclusive income growth identified for on-farm testing.

2015: Strategies for enhancing farmer access to scalable technologies and enterprise options developed and tested, including ICT-enabled information centers.

2016: Decision guides for effectively transmitting and scaling out profitable and more sustainable options developed, and mechanisms for accelerated diffusion to large numbers of farmers implemented.

2016: Early adoption studies conducted in selected hubs, on- and off-site impacts of integrated innovations on food security, income growth, gender equity, and sustainability evaluated, and results shared with partners.

2014-16: Partner efforts to scale out successful interventions through public–private partnerships, NGOs, change agents and governments facilitated in all hubs.

Linkages with other SIs

SI 2 shall have strong linkages with (a) SI 1 with regard to geo-spatial information on poverty and socioeconomic profiles in target environments, as well as knowledge on livelihood strategies and sources of income growth in different maize-based systems; (b) SI 3 in relation to decision guides, best-bet technologies, and CA practices; and (c) SIs 4 and 5 for identification of varieties that are best suited under different agronomic situations and management practices.

What's new in this initiative?

The key innovation and guiding principle for SI 2 is the integration of best-bet technological options and institutional innovations to address multiple constraints that lock smallholder farmers into a nexus of poverty and land degradation—a threat to the livelihoods of both current and future generations. The pluralistic approach goes beyond addressing constraints in maize production and aims to tackle system-level challenges that undermine productivity growth and sustainable intensification within the maize-based production systems.

The approach will be implemented using the principles of innovation systems that bring together viable and locally adapted technologies and leverage local and scientific knowledge for sustainable intensification and income growth. Such systems incorporate researchers and extension agents, farmers, input suppliers and output market entrepreneurs, credit providers, machinery manufacturers, local policy makers, and other important stakeholders.

Targets and impact estimates

The SI will target six major maize systems in Africa, Asia, and Latin America with high concentrations of poverty and where maize is the primary crop (Figure 5). Current work is taking place in three of these systems (maize–beans in Latin America and the Caribbean; maize mixed systems in sub-Saharan Africa; highland mixed in South Asia), and the plan is to strengthen existing work and scale out to the other three maize-based systems (upland intensive mixed in southeast Asia; highland temperate mixed in eastern Africa; maize–root crop in West and Central Africa). Through the combined emphasis on testing, identifying, optimizing, and scaling out the best that the CGIAR has to offer for maize-based systems, it is estimated that an increase in net income of at least USD 90 per year is feasible for target families; the improved practices can be scaled out to 3 million smallholder farmers by 2020 and 15 million by 2030. This will give between 15 and 75 million people a combined benefit of USD 270 million by 2020 and USD 1,350 billion by 2030. The benefits include maize yield increases of at least 15% in the high production areas of Asia and Latin America, and an average 20% yield increase in the low productivity systems of sub-Saharan Africa. These benefits will emerge through closer partnerships with governments, NGOs, and other partners.

Other issues

Gender

Women are important players in maize-based farming systems and represent one of the most vulnerable groups that have not benefited from agricultural technologies in the past. This SI will ensure that at least 50% of women farmers and 50% young adults (the two groups are not exclusive) in the hub areas undertake participatory technology evaluation to increase the development leverage of proposed interventions. The strategy for adaptation and diffusion of technologies and inputs will take into account the specific constraints and technology choices of men and women farmers (nutrition, cooking, storage, market) of maize and other crops within the system.

Evidence from other regions shows that women farmers should benefit from labor-saving techniques, adoption of more profitable practices, and value chain innovations, while the reduction in drudgery should help to keep young adults on the land. Labor-saving innovations will particularly benefit families affected by HIV-AIDS and are likely to increase school enrollment and attendance for children. The incorporation of agroforestry species into the systems will provide a source of firewood, thus reducing the time needed for fuel collection—an activity largely assigned to women and children. Even female wage workers may benefit from productivity growth—there is potential for increased labor demand in weeding (initially) and harvesting operations, even if labor-saving options reduce demand in land preparation and planting.

Women, elders, and young adults will play an important role within the innovation systems in defining avenues of innovation—evaluations of technology options by these groups will be applied preferentially by those setting priorities for research and technology development within the innovation system.

Modernizing agriculture through use of ICT in the delivery of more precise and timely information will also make farming an attractive option to young adults.

Capacity building

Capacity building for research-for-development partners—both from within the hub focal area and outside it, and including regional and international partners—will be an important activity, and will underpin the efforts to scale up and scale out the methodologies and concepts developed in SI 2.

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Strategic Initiative 3.
Closing the yield gap through smallholder precision agriculture

Value proposition
Through a network of change agents and modern communication tools, empower 20 million smallholders to manage their crops in a more profitable and environmentally friendly manner, thereby providing food for 150 million poor maize consumers while reducing the environmental foot print.

Estimated impact	2020	2030
Maize production	1.2 million t	9.6 million t
Annual savings in N fertilizer	150,000 t	600,000 t
Income	USD 240 million	USD 1,790 million
Benefit to the poor in the maize-based systems	The target area includes 620 million maize-dependent poor. At least 100 million of these people will benefit directly from the initiative.	
Benefit to the environment	Reduced nitrate leaching and nitrous oxide emissions in areas with ineffective fertilizer use; reduced soil nutrient depletion in areas with under-application.	

Justification
General background
Inadequate crop management practices are often major factors limiting farmers' maize yields, seriously reducing the economic returns to purchased inputs and labor, while also eroding the value of public and private investments in crop improvement. Investment in research on crop management—at both the international and national levels—has lagged behind that in germplasm development during recent decades. As a result, change agents and farmers in developing countries are often insufficiently aware of the potential gains from good and precise crop management.

Decision guides showing the effects of different management practices on crop yields and profits in diverse cropping systems can help change agents and farmers build new knowledge. For example, guides that describe how poor weed control affects not just yield but also reduces the return from applied fertilizer and increases the risk of economic losses are needed to supplement nutrient management guides. Stress-tolerant varieties can further reduce the risk of crop failure, strengthening farmers' incentives to invest in additional inputs such as fertilizers and irrigation, and to maximize economic returns.

One way to enhance the effectiveness of such products involves the development and use of geo-referenced databases on soil quality, market prices, availability of inputs, and weather information. Access to these data enables extension services, commercial providers, and public and private aid organizations to better target improved technologies. In addition, new information and communication technologies (e.g., targeted SMS text messages) show great potential for providing farmers with location-specific recommendations.

Why international agricultural research?
Regional and cross-border evaluation of field problems can greatly assist in diagnosing productivity constraints more rapidly and precisely, especially within the same cropping system and agro-ecological zone. International research can greatly facilitate this work by designing and distributing regionally

coherent exploratory diagnostic trials, together with trial management protocols and diagnostic information; access to this facility enables partners, including farmers, to identify maize yield constraints and quantify their effects under local conditions. Once established in farmers' fields, the trials become a resource for research while also serving as learning sites for farmers and extension agents. Results from the international trials can be incorporated into geo-referenced databases containing the various layers of knowledge (e.g., soil maps, weather forecasts and market information) that are needed for a systems approach to crop management. In addition to helping strengthen urgently needed agronomic research capacity and enhancing information and knowledge flow, an international network of agronomists will foster the integration of crop improvement and agronomy by providing feedback on key management practices and plant traits needed to make maize-based cropping systems more sustainable.

Lessons from past research

There are striking differences in fertilizer use on the maize crop in the high-yield potential areas of Asia and Latin America and the rainfed systems of sub-Saharan Africa. Whereas an average of 73 kg/ha of nutrients were applied across all crops in Latin America, 100 kg/ha in South Asia, and 135 in East and Southeast Asia (FAO 2004), fertilizer use in sub-Saharan Africa (excluding South Africa) in 2007 was less than 7 kg/ha of nutrients (calculated from data of FAOSTAT—http://faostat.fao.org) although it is likely that about 17 kg/ha of nutrients were applied to maize (based on estimated fertilizer use in maize—FAO 2002).

While it is commonly accepted that nutrients are the major limiting factor to crop productivity in sub-Saharan Africa, fertilizer's agronomic potential is often unrealized because of poor land and crop husbandry practices. Many "poor" management practices (late application or inadequate doses) often stem from farmers' efforts to reduce risk (Kelly 2006). It is crucial that farmers understand the factors that increase risk and/or reduce crop responsiveness to fertilizer (seeding date, weeding, tillage, timing of fertilizer application) if they are to achieve levels of management that allow the application of nutrients without undue risk.

While market and political risk are important (these are addressed in SI 1), reducing the risk associated with weather, especially rainfall, through crop and soil management options and through better information on weather forecasts can raise the profitability of fertilizer use and crop productivity. Two particular avenues for addressing risk are response-farming techniques and simulation models; lessons from these tools need to reach many more farmers (Kelly 2006).

In higher-productivity environments of Asia and Latin America fertilizer use is often excessive; this reduces the profitability of crop production and also increases environmental risks of nitrate leaching and eutrophication. The efficiency of use of nitrogen is commonly 30% or less, even though levels of over 80% are technically feasible (Raun and Johnson 1999). Highly-efficient systems will depend on concurrently improving several avenues to efficiency—including application methods and fertilizer formulations, use of crop varieties that are more efficient in nitrogen absorption, and methods to diagnose and apply needed levels of fertilizer (taking into account spatial variability in soils).

While present recommendations for economic phosphorus fertilizer applications are generally good once laboratory analyses have been calibrated with field studies, results with nitrogen recommendations are not as good or precise. In recent years researchers have worked with different methods to directly assess crop nutrient requirements; these methods range from observing leaf color (in rice), use of chlorophyll sensors, and use of remote sensing devices (either satellite-installed or hand-held), to predict nitrogen and phosphorus responses. Results to date have been especially promising for nitrogen response prediction in wheat for both irrigated and (especially when linked to weather data) rainfed systems (Raun et al. 2002). Studies are underway to adapt the approaches for maize. Other nutrient deficiencies and responses may be identified by leaf reflectance, using different wavelengths.

Researchable issues

- The prevalence and distribution of farm-level maize yield constraints and the relative importance of management (knowledge and precision) and inputs.
- Socioeconomic factors that prevent smallholder farmers from adopting precision management of maize in different farming systems and countries.
- Enhancing the maize crop's efficiency in using applied nitrogen and phosphorus while reducing the risk of economic losses under different scenarios for the most important smallholder maize production systems of the developing world.
- Opportunities for adapting precision agriculture approaches used in the developed world, including low-cost diagnostic equipment, to improve targeting of recommendations at the landscape or district levels in the developing world.
- The feasibility of decision guides linked to current and new GIS databases for disseminating information efficiently to farmers, and of linking the guides to media such as SMS messaging protocols.
- Enhancing the definition of maize productivity constraints by linking spatial data with satellite imagery.

Outputs

1. Information on farmers' maize yield constraints in different environments, readily available to partners in a geo-referenced database to help target improved technology (links to SI 1).
2. Decision guides for maize crop management, developed locally with support from international partners and disseminated through various communication strategies, ranging from facilitated farmer-to-farmer exchange to web- and SMS-based tools.
3. An international network of researchers and development agents, focused on sharing information about maize crop management.
4. Web platform for receiving feedback from development partners, managing trial information and shipments, and sharing best practices.
5. Methodologies and decision guides for more accurate targeting and application of nitrogen and phosphorus fertilizers, taking into account spatial variability and weather forecasts.
6. Documented results on the use of web- and SMS-based crop management decision guides in areas where poverty is prevalent but cell phone service is available.

Research and development partners

This initiative will involve research collaboration between at least five international centers (CIMMYT, CIAT-TSBF, ICRISAT, IITA and IRRI) and various advanced research institutes, including Cornell University, USA; Stanford University, USA; Oklahoma State University, USA; the University of North Carolina, USA; the University of Adelaide, Australia; the International Plant Nutrition Institute (IPNI); Hohenheim University, Germany; ICAR, India; CAAS, China; and EMBRAPA, Brazil. The Alliance for a Green Revolution in Africa (AGRA) will also participate through many of its current projects. The involvement of the private sector, especially companies dealing with new information and communication technologies, will also be crucial to the success of the initiative.

National research and extension systems of the countries where the target farming systems are important will play a critical role in the international exploratory diagnostic trials. These systems include universities, the private sector (i.e., seed companies and farm implement manufacturers) and both national and international NGOs. Farmers in the target communities will also be important development partners.

Outcomes

- Solutions to regionally important stresses identified through the international exploratory diagnostic trials.
- Change agents in developing countries are better equipped to diagnose maize production problems and give reliable and simple messages to farmers on “best-bet” crop management practices.
- Smallholder farmers managing maize-based systems in developing countries have a better understanding of factors that limit maize and system productivity, and the interactions between these factors.
- Increased nutrient use efficiency in high productivity maize systems of Asia and Latin America.
- By using decision guides, alone or with assistance from extension services, farmers are able to increase the productivity and profitability of their maize crops.
- Increased benefit to farmers from using fertilizer and improved varieties.
- Seed companies and other input suppliers are better able to target their products to particular agro-ecological niches, thereby making the maize value chain more efficient.

Key milestones

2011: International exploratory diagnostic trials are designed, protocols prepared, and trial sets distributed to focal areas of the MAIZE Sustainable Systems Initiative and to other field sites managed by research for development partners.

2011: Website initiated for reception of trial data and demonstration of geo-referenced data.

2012: Decision guides for nitrogen application, based on the use of small remote-sensing devices, are developed for high-productivity conditions in Mexico and South Asia.

2012: Data obtained from at least 500 exploratory diagnostic trials in Africa (200), Asia (200) and Latin America (100).

2012: Web- and SMS-based decision guides tested in two countries with farmers, national extension systems and commercial providers.

2013: National extension systems, including both public organizations and NGOs, in the initial target countries incorporate the diagnostic trials into their own work.

2013: Web- and SMS-based decision guides for applying nitrogen, based on crop simulation modeling and weather forecasting, tested in three districts in sub-Saharan Africa.

2014: Decision guides for nutrient management, based on results from the exploratory diagnostic trials, used in at least five countries.

2015: Decision guides developed for application of phosphorus to maize under different moisture conditions.

2016: At least 150,000 smallholder maize farmers adopting improved management practices as a result of knowledge gained through the initiative.

Linkages with other Strategic Initiatives

SI 3 will have strong linkages with SI 1 (Socioeconomics and policies for maize futures) in documenting and understanding community and farmer evaluations of the importance of different limiting factors to maize productivity, as well as in the ex-ante analysis of the feasibility of solutions to the most limiting factors in the different environments. There will also be close linkages with the national partners involved in SI 4 and SI 5, for effective utilization of relevant, locally adapted maize varieties along with suitable agronomic management practices.

Collaborative activities

The focal activity of the SI will be the development and deployment of a diagnostic trial to help farmers, change agents, and researchers, both national and international, to identify the major factors limiting maize crop productivity, as well as key interactions among factors. The on-farm diagnostic trial will be used for data collection and as a learning module for farmers and change agents. Trial composition will be regionally defined, taking into account knowledge of particular limiting factors in the region, and will vary by farming system. Trials will be prepared and distributed nationally. Typical trial conformation will include a treatment representing local common practice (the farmers' check), a full "best-bet" recommended package (which differs from the common farmer practice in those components that may limit yield, efficiency, and profitability), and a series of treatments where one component of the package is omitted.

Depending on the region, recommended packages will include: a recommended and adapted high-yielding variety; nitrogen, phosphorus and potassium fertilizer; optimum seeding date; adequate weed control; surface mulch; lime; standard pest control practices. Each of these factors will be omitted in one of the treatments. Yield data from the plots will be supported by observations on disease and pest incidence and by the analysis of foliar samples to detect micronutrient deficiencies.

An important caveat is that the trials are aimed to identify problems and constraints, not to identify solutions. Any necessary research to identify socially and economically viable solutions will constitute a subsequent phase of the research process, guided by a thorough analysis of possible solutions to problems and opportunities, and by ex ante socioeconomic analysis (linked to SI 1). For instance, even though the diagnostic trials will use inorganic fertilizers as sources of nutrients, this does not imply that recommended solutions might not rely on other nutrient sources (manure, biological nitrogen fixation, etc.).

Management of the diagnostic trial will commonly be through local change agents who will receive specific training, through the application of diagnostic guides on pests, diseases, and nutrient deficiency symptoms, and by advice through a cell phone and web-based "help-desk" capable of responding promptly to queries on trial management, problem identification and solution. Trials will be replicated in target communities with each replication on a different field to sample local spatial variability. They will also serve as focal points for farmer field days and discussion groups. Farmer evaluation of the trials, disaggregated by gender and age, will permit researchers to ensure equity in the development of technologies and recommendations for the target areas.

Trial data will be used to set priorities for applied research and technology dissemination, and will be supported by economic analysis and simulation modeling to identify opportunities for further system productivity enhancement. A key element of the applied research agenda is likely to be the development of weather-responsive fertilizer recommendations that can be disseminated easily to farmers through cell phones and other communication methods.

What's new in this initiative?

- To date, no international diagnostic trial dealing with more than nutrient deficiencies and responses has been conducted to evaluate the effects of different crop management components on maize yield across the farming systems targeted in this initiative.
- A network of maize agronomists will enhance research capacity in target countries.
- The diagnostic trials should prove useful to farmers and extension agents as aids to learning and will likely be incorporated into the work of national partners.
- Cutting-edge sensor technology for diagnosing nutrient needs will be introduced to small-scale farmers in the developing world.

Targets and impact estimates

Fourteen systems will be included in this initiative (Figure 5). Given the leverage of new communication tools, we estimate that by 2020, 2 million farmers in Asia and Latin America will have increased their maize yields and profitability, and 15 million by 2030. In Africa, 500,000 farmers will have adopted higher-yielding practices by 2020 and 5 million by 2030. In the higher-yielding environments of Asia and Latin America this will result in average yield increases of 15%, while reducing farmers' use of nitrogen fertilizer by 25%. In the more variable and lower-yielding environments of sub-Saharan Africa, the trials and decision guides will lower farmers' productions risks and boost their input use, with a minimum average yield increase of 25%.

These advances will translate into 1.2 million tons more maize grain by 2020 and 9.6 million tons by 2030, and they will be accompanied by savings of at least 150,000 tons of nitrogen fertilizer in 2020, and 600,000 tons in 2030. The total value of these benefits will amount to USD 240 million per year in 2020 and USD 1.8 billion in 2030.

Other isssues

Gender

The gender of farmers participating in and evaluating the exploratory diagnostic trials will be one of the variables recorded. Where possible, feedback on the trials will be assessed separately for female and male farmers, to understand and address gender-specific constraints. These observations will then feed into the design of the research to overcome the limitations identified in the diagnostic trials, and again the gender disaggregated data on possible solutions and options will be used to evaluate and define research directions.

Capacity building

Capacity building will be an important component of the SI, and will include knowledge development in farming communities and among change agents on the factors limiting crop productivity. Research partners will receive training on potential and innovative solutions to productivity limitations, on the management of efficient applied research programs and on the use of the outputs of simulation models to enhance ex ante analysis of research directions.

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Strategic Initiative 4. Stress-tolerant maize for the poorest

Value proposition

Provide maize food security and reduce production shortfalls for at least 36 million and ideally over 100 million of the poor in Africa, Asia, and Latin America whose crops suffer the effects of an array of abiotic (especially, drought) and biotic stresses, accentuated further by global climate change.

Estimated impact	2020	2030
Benefit to the poor	The target area includes an estimated 560 million maize-dependent poor	
Production increase	1.7 million tons of maize grain	4.5 million tons of maize grain
Impact on diet	Adding 5% to the diet of 560 million maize consumers	Adding 13% to the diet of 560 million maize consumers
Value addition	USD 420 million	USD 1,200 million
Benefit to the environment	More reliable maize yields provide incentives for farmers to reduce maize area, diversify crop production, and replenish soil nutrient deficits	
Others	Reduced price fluctuation in drought years; reduced need for imports and food aid; greater dignity for people in droughted areas	

Justification

General background

Maize is the basis for food security in some of the world's poorest regions in Africa, Asia, and Latin America, yet yields are often extremely low, averaging approximately 1.5 tons per hectare—about 20% of the average yield in developed countries. Yields in low-productivity rainfed environments are severely limited by both abiotic and biotic stresses; often an abiotic stress such as nutrient deficit is a triggering factor for biotic stress factors, including leaf diseases, ear rots, and insect outbreaks. Recurrent drought, low levels of fertilizer use, and low adoption of improved varieties all contribute to low yields. Improvement in the levels of defensive traits, including tolerance to drought, low N fertility, waterlogging, heat and acid soils, along with resistance to diseases, insects and parasitic weed *Striga*, can significantly reduce the risk associated with planting under rainfed conditions and may promote the use of other inputs and improved management practices.

Abiotic stresses

In southern Africa, the 2002–03 drought resulted in a food deficit of 3.3 million tons, with an estimated 14 million people at risk of starvation (WFP 2003). In 2005–06 and again in 2009 severe droughts struck maize farmers in eastern Africa; likewise drought regularly affects crops in dry belts of Mexico and Central America and in parts of western and southern India. Farmers affected by recurrent drought tend not to invest in yield-enhancing inputs, and respond instead by planting a large area to low-input maize in the hope of ensuring household food security. Stabilizing and increasing productivity in the face of recurrent drought can promote cropping diversification, better management of soil fertility, and income generation.

Nitrogen—either applied as fertilizer or from organic sources like manure or legumes—is one of the most important nutrients for plants, but small-scale maize farmers often cannot afford chemical fertilizer. African farmers, who are chiefly smallholders, use less than 10 kilograms of fertilizer per hectare of crop land, on average. Maize varieties that tolerate drought and nitrogen-poor soils will reduce farmers' risk, provide incentives to invest in inputs like fertilizer, and allow them to attain food security on a smaller area, freeing up land and labor to grow cash crops, and reducing pressure to open new land.

The interlinked soil fertility problems of acidity, aluminum toxicity, and low phosphorus availability constrain yields on about 4 million hectares of cropland worldwide. Also, because maize is grown predominantly as a rainfed crop, increased rainfall variability from climate change (Hulme et al. 2001; Stige et al. 2006) will exacerbate losses from drought and flooding, causing production and price fluctuations (Jones and Thornton 2003). The largest impact on consumer prices comes from relatively favorable production regions, such as areas with an average of 500–800 mm rainfall, where unexpected drought can significantly cut production.

Breeding for drought tolerance was assessed to have the highest return to investment not only in sub-Saharan Africa (Langyintuo et al. 2008) but also for rainfed maize production in Asia (Gerpacio and Pingali 2007), where drought-tolerant varieties have an important role in meeting the burgeoning demand for feed maize. Maize offers great potential as a rainfed crop to follow rice at the end of the monsoon, or as the main crop in areas where water availability is marginal or inadequate for rice. To realize this potential, maize varieties are needed that tolerate drought late in the growing cycle, during flowering, and at grain filling. At the initial meeting of the Asian Hybrid Maize Consortium in April 2010, Asian national research systems and seed companies urgently requested CIMMYT's assistance in developing drought-tolerant maize.

Combinations of stresses are also particularly damaging to crops (Mittler 2006). The combination of heat stress and drought, which leads to very high leaf temperatures and rapid desiccation from stomatal closure, is likely to increase in some regions with global climate changes. CIMMYT researchers have observed that many lines that are tolerant to drought alone perform poorly under conditions of drought combined with high temperature. This indicates that joint, concurrent screening for both stresses will be required to identify tolerant materials, and that tolerance to stresses in combination cannot necessarily be predicted from reaction to individual stresses in isolation. The combination of waterlogging early in the season (which impedes root development) and late-season drought occurs commonly in some areas of South and Southeast Asia. The combination of excess rainfall and poor drainage is also a severe constraint to maize productivity, particularly in Asia during the wet season in areas heavily dependent on monsoon rainfall. It results in yields that are approximately one-half to one-third lower in the rainy season than those under irrigated production on the same lands in the dry season. The need for improved germplasm with tolerance to combinations of abiotic stresses (drought + heat; waterlogging + drought) warrants the development of new screening/phenotyping approaches and breeding strategies.

Biotic stresses
Losses due to abiotic stress are often compounded by the high incidence of diseases, insect pests, and weeds, which on average can reduce yields by more than 30%. An estimated 54% of attainable yield is lost annually to diseases (16%), animals and insects (20%), and weeds (18%) in Africa. Similar losses have been observed for Central and South America (48%) and Asia (42%) (Oerke, et al. 1994; Oerke 2006). Efforts to reduce maize losses from diseases and insect pests through resistant crop varieties offer tremendous opportunities for increasing and stabilizing maize productivity. Enhancing and stabilizing maize productivity in the face of recurrent drought, insect pests, and diseases could increase food supplies, lower food prices for consumers, and improve rural incomes, household food security and nutrition (Wiebe 2001).

Maize diseases of global or regional importance include southern corn leaf blight (*Bipolaris maydis*), southern rust (*Puccinia polysora*), northern corn leaf blight (*Excerohilum turcicum),* common rust (*Puccinia sorghi*), gray leaf spot (*Cercospora* species), stalk and ear rots caused by *Diplodia* and *Fusarium*, and kernel and ear rots caused by several *Fusarium* and *Aspergillus* species. Fungal toxins (mycotoxins) also contaminate grain, thereby reducing grain quality and safety. Diseases that are particulary important to Asia are the downy mildews, banded leaf and sheath blights (BLSB) and post flowering stalk rots (PFSR). For Latin America, the tar spot complex and the corn stunt complex diseases are of particular importance. Biotic stresses limited to Africa include maize streak virus (MSV) and the parasitic weed *Striga* (*Striga asiatica* and *S. hermonthica*).

The frequency and severity of disease epidemics is dynamic, and while some currently important diseases may become less important as resistant cultivars are developed and deployed, others presently considered unimportant may become more prevalent with changes in climate, cropping practices, and introduction of new germplasm. For example, increased adoption of zero tillage and conservation agriculture has resulted in increased incidences and severity of gray leaf spot (GLS—*Cercospora zeae-maydis).* In Africa, yield reductions of 30–60% have been attributed to GLS, depending on germplasm and environmental conditions (Ward et al. 1997). GLS is now becoming an important disease globally, with high incidences reported in Nepal, China, Colombia, Mexico, Brazil and several countries in Africa. A similar situation has been observed for the tar spot complex in Latin America, where heavy losses have recently been noted in El Salvador, Guatemala, Mexico, Colombia, and Nicaragua. Research is needed to document the likely effects of predicted climate changes on pathogen dynamics and their agricultural impacts, along with the effects of changing cropping systems (such as increased adoption of conservation agriculture) on disease and pest dynamics (Bigirwa et al. 2001; Ward et al. 1999).

Insect pests reduce maize production by directly attacking roots (rootworms, wireworms, white grubs, and seed-corn maggots), leaves (aphids, armyworm, stem borers, thrips, spider mites, and grasshoppers), stalks (stem borers, termites), ears and tassels (stem borers, earworms, adult rootworms and armyworm), and grain during storage (grain weevils, grain borers). Stem borers are the most damaging group of insect pests in maize cultivation and account for an estimated average annual loss of 18% (De Groote 2001). Two species of stem borers, *Chilo partellus* and *Busseola fusca*, are common biotic constraints to maize in eastern and southern Africa, while in west and central Africa the stem borers *Sesamia calamistis, Eldana saccharina* and *Mussidia nigrivenella* are the dominant insect pests of maize. In addition to pre-harvest losses, post-harvest losses of up to 80% from grain weevils (*Sitophilus zeamais*) and the larger grain borer (*Prostephanus truncatus*)have been reported in farm stores in the tropics. Minimizing such losses will significantly contribute to nutrition and food security.

Why international agricultural research?

Large seed companies often find drought-affected areas unattractive for investment due to farmers' low or unpredictable purchasing power. Publicly funded agricultural research is needed to fill this gap. However, many drought-affected countries are classified as low or lower-middle income, with weak national research systems that need capacity building and engagement with international agricultural research. Even the stronger national research systems have tended not to adapt drought-tolerant sources from the CG system to their own conditions because of the complexity of the task.

Collaboration between international agricultural research, national research systems, the private sector, community-based organizations and non-governmental organizations can generate the required critical mass for research and delivery. Examples already exist, particularly in Africa, where some national research systems are involved in variety adaptation and release and local seed companies are collaborating in low-cost hybrid and open-pollinated variety (OPV) seed production. As well, social safety net programs funded by governmental and non-governmental organizations are engaged in accelerated dissemination of seed to the poorest and most drought-affected farmers.

Progress to date and lessons learned

CIMMYT and IITA lead the development of maize varieties tolerant to drought and nitrogen-stress for the developing world. The two institutions are increasing their efforts to generate germplasm tolerant to waterlogging, acid soils, and high temperatures. Selection for yield under such stress is the focus of the organizations' breeding efforts in sub-Saharan Africa, with strong programs for tropical systems in Asia and Latin America as well. Breeding at CIMMYT for drought-prone and low-fertility environments started over 30 years ago (Edmeades et al. 1999) and has resulted in hybrids that equal the best commercial products under optimal conditions and out-yield them by up to 100% under severe drought and nitrogen stress (Bänziger et al. 2006). Populations, inbreds, and hybrids with high levels of tolerance to acid soils (Welcker et al. 2005) and vegetative-stage flooding have been identified (Zaidi et al. 2007), and QTLs for waterlogging tolerance are being mapped.

The key to this progress has been the use of managed stress screening. The Drought Tolerant Maize for Africa (DTMA) project, funded by the Bill & Melinda Gates Foundation and implemented by CIMMYT, IITA and African national research systems, is a comprehensive breeding, capacity building, and seed production initiative that aims to provide 25% of farmers in sub-Saharan Africa with seed of drought-tolerant varieties by 2016. This Strategic Initiative will build on the successes of this and smaller stress-tolerance breeding projects such as the BMZ-funded project "Abiotic stress-tolerant maize for increasing income and food security among the poor in eastern India and Bangladesh", and extend them to other regions.

Several important lessons have been learned from this long history of stress tolerance breeding. One is that success in developing abiotic stress-tolerant germplasm requires close collaboration between scientists in diverse disciplines—including breeders, physiologists, geneticists, and soil scientists—to ensure that appropriate traits are screened for, screening systems are optimized, and appropriate germplasm is used. The need for high-quality phenotyping and physiology support is a key reason for grouping into a single strategic initiative the development of abiotic stress-tolerant germplasm for a range of stresses.

Because most tropical maize fields are rainfed, tolerance to intermittent abiotic stress such as drought, heat, and waterlogging is also critical. Based on the experience in temperate regions, wide-scale testing networks are critical for achieving this resilience, but are expensive to operate. Clearly, larger multi-location variety testing networks are needed in tropical and subtropical maize breeding, and can only be formed economically by linking the testing efforts of small companies, CIMMYT, IITA, and NARSs to achieve economies of scale.

Although hybrids are substantially more stress-tolerant than open-pollinated varieties, and local private seed companies are key partners in delivering hybrid seed to smallholders, low seed yield of inbred parents of hybrids and lack of technical skill in seed production by small seed companies can prevent the profitable production of stress-tolerant hybrids. This SI will build on and extend to other regions the strong efforts already underway in Africa to support the technical and business capacity of small seed companies in stress-prone regions, to reduce production costs by improving the *per se* performance of inbred lines produced by our breeding programs, and to fully explore novel low-cost hybrid seed production systems.

Another important lesson is that abiotic stress tolerance in itself is not sufficient to ensure adoption; farmers require tolerance to regionally important diseases, insect-pests and parasitic plants, and responsiveness to favorable condition in years in which stress is not severe. Thus, products of the

CIMMYT and IITA breeding programs are selected for tolerance to important biotic stresses (GLS, MSV, ear rots, *Striga,* turcicum leaf blight and rusts, among others). Past maize research at CIMMYT and IITA has tended to focus on the early stages of quantitative trait locus (QTL) mapping for biotic stresses, but stopped short of delivering the validated, tightly linked or gene-based markers needed to breed efficiently for biotic stress tolerances that are oligogenically inherited. This SI will prioritize the fine-mapping and positional cloning work needed for development of breeder-ready, low-cost SNP markers for resistance to MSV, GLS, *E. turcicum*, and other key adaptive diseases (BLSB, PFSR, downy mildews), allowing the rapid introgression of an appropriate suite of resistances into stress-tolerant lines.

Efforts to identify donor germplasm and tagged alleles conferring resistance to yield-limiting leaf and ear diseases need to be increased, especially for emerging diseases (tar spot in Latin America; BLSB in Asia), for which little breeding work has been done. CIMMYT, IITA, NARS, and private-sector programs need to join forces to ensure effective hot-spot and inoculated screening for donor identification, and to share the cost and effort required to develop production markers for both oligogenically and polygenically controlled biotic stress resistances. Significant progress has been made to identify stable genetic resistance for most major maize diseases and for *Striga* (Gerpacio and Pingali 2007; Lal et al. 2000; Bosque-Perez 2000; Pratt and Gordon 2006; Menkir et al. 2007; Welz & Geiger 2000).

Available sources of resistance must be confirmed in multiple environments to facilitate identification of the most suitable resistance genes and donors for use in breeding programs. CIMMYT has started multilocation phenotyping of elite inbred lines for response to several diseases of economic importance, including GLS, *E. turcicum*, MSV; ear rots, southern corn leaf blight, and southern and common rusts. Preliminary results have identified several good sources of resistance for all diseases and across locations. Maize inbred lines with diverse genetic backgrounds and differential disease reaction patterns developed at CIMMYT and IITA will form an association panel for testing in multiple locations in sub-Saharan Africa. Similar efforts are being planned for regionally important diseases such as bacterial leaf and sheath blight and downy mildew and PFSR in India.

Progress in breeding for host plant resistance to economically important insects has been slower than breeding for disease resistance. However, CIMMYT and IITA have developed several insect-resistant populations (to stem borer and storage pests) which have been successfully used in Kenya and Nigeria and can be used to introgress insect resistance into agronomically elite materials with high levels of abiotic stress tolerance and high yield potential. Several inbred lines have been developed combining resistance to stem borers and storage pests. Wide testing of these materials in Kenya, Tanzania, and Uganda is taking place as part of the Insect Resistant Maize for Africa (IRMA) project, resulting in the release of insect-resistant hybrids. Efforts are being made to combine insect resistance and drought tolerance, using doubled haploid technology to rapidly develop inbred lines combining insect and drought tolerance. Identification of QTLs and associated gene-based markers for resistance will facilitate the rapid conversion of agronomically elite inbred lines to higher levels of tolerance.

Current approaches to improve insect and disease resistance at IITA, CIMMYT, and in national programs are based largely on phenotypic selection and have resulted in populations with improved resistance to MSV, leaf disease and storage insects. However, these approaches are inefficient when inoculated screening is unreliable or expensive and natural occurrence of the stress is intermittent. They are also slow and expensive when the objective is to convert elite, drought-tolerant inbreds to higher levels of tolerance. Quantitative trait loci (QTL) associated with resistance to many diseases (NLB, downy mildew, SLB, rust, GLS, and many other diseases) and insects have been identified and mapped in maize (Wisser et al. 2006; Garcia-Lara et al. 2009; Krakowsky et al. 2004), making marker assisted selection (MAS) a potentially viable strategy to improve resistance to these pests.

However, few molecular markers are being used in breeding programs, largely because little effort has been put into breeder-friendly marker development. This requires the establishment of a fine-mapping pipeline that will identify usable polymorphisms tightly linked to the genes of interest. Recent reductions in the cost of genotyping have made the use of marker-assisted selection (MAS) for this purpose feasible for small commercial and public breeding programs in Africa. A systematic pipeline designed to deliver breeder-ready markers for these and other leaf and ear diseases and storage pests should now be established to support rapid conversion of elite drought-tolerant and other inbred lines to higher levels of biotic stress resistance.

CIMMYT has developed several populations that can be used for marker identification, validation, and fine mapping. These need to be phenotyped in multiple environments and genotyped at high density to to identify suitable markers for use in selection. Marker development depends on good phenotypic data to make reliable marker trait associations. To collect quality phenotypic disease data suitable for marker identification, CIMMYT has established disease phenotyping hubs in southern Africa and Mexico and equipped them with misting systems to create ideal microclimatic conditions for foliar disease development. These are being used to screen elite inbred lines that form part of an association mapping panel for resistance to GLS, NCLB, and SCLB. There are plans to establish similar hubs in West Africa and Asia. Initial QTL localization will be done with these panels, which will also identify donors for use in subsequent fine-mapping. Marker development will benefit from use of standardized disease establishment and scoring protocols across CIMMYT, IITA, NARSs and commercial partners.

Researchable issues

- Further refinement of target regions with the greatest return to investment in drought tolerance breeding, and specific needs of resource-poor women and men in those regions.
- The physiological and genetic (mostly polygenic) bases for improved yield under drought, nitrogen, waterlogging, acid soils and heat stress, permitting the development of new selection systems and marker–trait associations useful for accelerating breeding progress.
- Determining the extent to which germplasm, selected for tolerance to single stresses such as drought, is tolerant to the same stress in combination with other stresses such as heat, and understanding the mechanisms for combined stress tolerance.
- Understanding the genetic control of key adaptive traits (mostly oligogenic biotic stress resistance traits).
- Improved high-throughput phenotyping approaches for component traits (spectral reflectance for growth analysis, water and nutrient uptake, rhizotron facility for root system analysis, isotope enrichment for water use efficiency (WUE), image analysis for growth and production, electrical conductivity and spectral reflectance for site characterization).
- Tagging genes/QTLs for key adaptive diseases (MSV, GLS, TLB, PFSR) and identification of breeder-ready markers for incorporating biotic stress resistance in elite germplasm.
- Harmonizing phenotyping assays for important biotic stresses to reliably identify donors and breeding materials with resistance to the target diseases.
- Gene-by-germplasm and gene-by-environment interaction of individual native and transgenic genes for stress tolerance with strong effect.
- Use of crop models and genetic analysis to assess the relevance and design of managed abiotic stress screening, and high-throughput phenotyping and genotyping to maximize genetic gains in the target environment and as climates change.

- Institutional weaknesses affecting the maize seed value chain in stress-prone environments and the feasibility of alternative seed production and dissemination approaches (OPVs, conventional and unconventional hybrids) to reach farmers in stress-prone areas that are less attractive to the private seed sector.
- The effects of predicted climate changes on pathogen and insect pest dynamics and their agricultural impacts. The effects of changing cropping systems, such as the rice–maize rotation, and increased adoption of zero tillage/conservation agriculture on disease and pest dynamics.

Outputs

1. Germplasm tolerant to drought, low nitrogen stress, acidity, waterlogging and heat stress that yields well under favorable conditions and has the necessary biotic stress resistance—for major maize production regions in Africa, Asia, and Latin America affected by these stresses. This will include:
    - Donors conferring high levels of abiotic stress tolerance for use in breeding locally adapted hybrids and OPVs.
    - Donors conferring high levels of resistance to key biotic stresses, particularly MSV, GLS, *E. turcicum, H maydis,* and *Striga.*
    - Hybrids and OPVs yielding at least 100% more than current varieties.[10]
    - Hybrids and OPVs with tolerance to combinations of abiotic stresses—in particular heat plus drought and waterlogging plus drought.
    - Inbred lines targeted at more favorable production regions, where sporadic droughts (>10% risk of crop failure) can wipe out significant production volumes and lead to income variation for farmers, country-level shortages, and price variations which affect poor consumers.

    Our strategy for inbred line development supports both hybrid and OPV production. Inbred lines—the principal products of CIMMYT and IITA pedigree breeding programs—are the building blocks of both hybrids and open-pollinated synthetic varieties[11]. Programs targeting stress-prone environments will thus produce hybrids for dissemination by seed companies and OPVs, which are primarily distributed by government seed units and NGOs, according to local demand and preference. The formation of synthetic varieties from elite inbred lines adds little to the total cost of breeding programs, and generates OPVs that are usually more productive than broad-based populations.
2. Innovative, low-cost hybrid seed production systems, involving crosses between narrow-based synthetics, between a synthetic and an inbred parent and between advanced marker-assisted recurrent selection (MARS) populations derived from high-yielding, proven double crosses. These low-cost, seed-production approaches will allow small seed companies to produce highly-vigorous, heterotic hybrids without the need to produce large amounts of seed of inbred lines, which can be a long and expensive process that becomes an important obstacle to hybrid seed production.
3. Internet-based information systems that identify the best available germplasm for various client groups, including breeders (seeking breeding germplasm from international agricultural research centers), seed producers (seeking stress-tolerant, finished varieties from national and international research systems), and governmental and non-governmental organizations (seeking seed producers of drought-tolerant varieties for seed relief).
4. Open-source breeding networks and a set of decentralized phenotyping sites to improve maize for tolerance to drought, nitrogen stress, and heat, using state-of-the-art phenotyping, doubled

[10] Currently sown varieties typically yield 1 ton per hectare or less under severe abiotic stress conditions, and in many instances fail.
[11] Synthetic varieties are OPVs produced by initially intermating inbred lines, then maintaining and increasing the variety via open pollination.

haploids, and innovative marker-based approaches designed for quantitative trait improvement. The latter include marker-assisted recurrent selection (MARS) and rapid-cycle genomic selection (GS) to dramatically shorten breeding cycles and increase rates of yield gain under drought and nitrogen stress conditions.

5. Tagged alleles with large effects on abiotic stresses, particularly nitrogen, drought, and heat, for use by public and private breeders in marker-assisted selection in varieties targeted for stress-affected environments. We will forge public–private partnerships for positional cloning and development of breeder-ready markers for large-effect native-trait alleles for these stresses.
6. Standard operating protocols, procedures and facilities established to phenotype maize germplasm for resistance to major biotic stresses:
   - Phenotyping hubs for major biotic stresses developed.
   - Standardized phenotyping protocols for major biotic stresses of critical importance established and published.
   - Well trained support staff capable of generating reliable data available to scientists, NARSs and seed companies.
7. Molecular markers for the introgression of major genes/QTL conferring resistance to key biotic stresses will be identified, developed, validated, and deployed:
   - Gene-based or tightly linked markers associated with resistance to major biotic stresses identified and delivered to breeders.
   - Markers for biotic stress tolerance routinely used to select in segregating generations in DTMA and related breeding programs.
   - Genes for biotic stress tolerance introgressed into drought-tolerant inbred lines.
8. The capacity of NARS and private-sector scientists to conduct biotic stress screening and develop multiple disease- and insect-resistant maize germplasm in their breeding programs will be strengthened.
9. Building on CIMMYT's current public–private partnerships (*Water-Efficient Maize for Africa with the African Agricultural Technology Foundation and Monsanto*, and *Improved Maize for African Soils with Pioneer*), humanitarian licenses for large-effect (>10%) transgenic technologies identified and sourced from private partners, introgressed into improved adapted germplasm, and validated in confined field testing with national research system partners where the necessary regulatory frameworks exist. Because of the extremely high cost of transgene development and deregulation, transgenic approaches will be used when (i) highly promising events are identified in commercial programs and (ii) partnerships can be formed to leverage the development pipelines and biosafety and deregulation investments made by major seed companies. MAIZE will also strive to strengthen close partnerships with selected countries in the developing world to enable establishment of bio-safety authorities and/or facilitating development of appropriate rules and regulations (as per internationally accepted protocols) to guide field testing of transgenic maize. Support to weaker national research systems, seed companies, and community-based organizations to register, promote, and disseminate stress-tolerant varieties through:
   - Production of parental seed stocks in regional foundation seed units to enable rapid scale-up of seed production by national research systems, seed companies, and NGOs.
   - Availability of appropriate product information about improved varieties for demonstrations and farmer education, so as to create a market demand for the new varieties.
   - Training in skills and strategies to effectively test, release, scale-up, and market new varieties.
10. Institutional innovations, seed market information, and policy recommendations that accelerate the diffusion of stress tolerant maize varieties into areas with a weaker private seed sector presence.

Research and development partners

CIMMYT and IITA have established collaborative germplasm development for drought and N stress, mostly with national research systems in sub-Saharan Africa, and CIMMYT has supported emerging efforts in Asia. This network needs to be strengthened, particularly in Asia where increasing yield levels and climate change greatly amplify production variations due to drought and heat, and for poverty pockets in Central America. Research collaboration will be sought with multinational seed companies and biotechnology organizations (building on successful collaboration with Monsanto, Syngenta, AATF and Pioneer) and advanced research institutes including those in the developing world (Brazil, China, India, Mexico) for positional cloning of relevant native-trait alleles and transgene sourcing and deployment. The basic requirements for engaging in transgenic trait research include: (1) royalty-free access for farmers in low and lower-middle income countries (or a significant number of such countries); (2) proof of concept for relevant (>10%) yield increases at the field level in maize or other crops; (3) a feasible deregulation strategy.

These partners include the wider range of national research systems, local seed companies, NGOs, and community-based organizations in drought affected countries in Africa, Asia, and Latin America, for local variety adaptation/selection, release, and scale-out to farmers in stress-prone environments. More effective interactions need to be built with development partners engaged with farming families and communities that do not receive adequate services—either from the private or the public sector—and have limited access to markets because of poverty and lack of political influence.

Outcomes

- Sufficient production increases in stress-prone environments to allow farmers to escape the poverty trap of recurrent failed harvests and enable them to obtain reliable returns on investments in seed, fertilizer, land and labor.
- Increased diffusion of improved technologies in stress-prone environments, to the benefit of farmers and local entrepreneurs.
- Reduced variation in maize production and more stable grain prices.

Key milestones

2011: Research collaborations formalized and collaborative breeding/variety testing networks extended to include as a minimum:
- Africa: six drought phenotyping sites, six N stress phenotyping sites, one heat phenotyping site, one acid soil phenotyping site.
- Asia: four drought phenotyping sites, two heat phenotyping sites, three waterlogging phenotyping sites. Tolerance to combined heat plus drought, and waterlogging plus drought, will be evaluated in at least one site for each combination.
- Latin America: two drought phenotyping sites, two N stress phenotyping sites, one acid soil phenotyping site. Tolerance to heat plus drought will be evaluated in at least one site.
- Disease and insect pest phenotyping hubs established in key countries in East and West Africa, and in Asia

2011: Target regions with the greatest potential return to investment in drought/heat tolerance breeding defined, based on available GIS data.

2011: Standard biotic stress screening protocols developed and shared with partners.

2012: Stress tolerant donors identified from existing databases and confirmed in phenotypic screening. Information made available on the internet and seed availability ensured.

2012: Managed stress screening sites operational and research staff trained in common protocols.

2012: Technicians and NARS scientists trained in the use of standard operating protocols for data collection and analysis so that disease and insect evaluations are uniform across locations; training also on using digital data acquisition tools for collecting accurate data and effectively managing and storing collected data (data management systems).

2013: Value chain analysis in stress-prone environment completed, and gender disaggregated farmer needs defined in six different regions (three Africa, two Asia, one Central America).

2013: Agreements made with relevant organizations to strengthen foundation seed supply of best stress-tolerant varieties at the sub-regional level.

2014: Improved phenotyping protocols implemented by all research partners (repeated in 2016).

2015: Breeder-ready markers for large-effect QTLs for biotic stress resistance made available.

2015: Institutional innovations, seed market information, and policy recommendations that accelerate the diffusion of stress-tolerant maize varieties promoted through various means.

2015: Target regions with the greatest potential return to investment on drought/heat/N stress tolerance breeding revised, based on updated GIS data, climate models and assessment of breeding progress.

2016: Efficient incorporation in adapted backgrounds of at least two transgenes for drought or nitrogen use efficiency, also initiation of contained field testing in appropriate mega-environments.

2016: Fine-mapping of alleles conferring improved N and heat stress tolerance completed, map-based cloning to develop gene-based markers in progress.

2016: Demand-driven support to partner countries for establishing biosafety authority and/or devising rules and regulations (based on relevant international protocols) to guide field testing of transgenic maize for key target traits.

Linkages with other SIs

There will be close operational coordination between SI 4 with its emphasis on tolerance to severe abiotic stress and food security, SI 5 with its focus on yield potential and cash grain production with optimized input use in more favorable environments in Asia and Latin America, and SI 9 with emphasis on the development of new breeding tools and approaches. Formal mechanisms to exchange information and genetic materials, including lines, populations, hybrids, and genes, will ensure that gains from stress tolerance breeding will benefit yield stability in favorable rainfed environments, and that the best available high-potential germplasm will be available for use in stress-prone environments. Tools developed in SI 9 will be implemented as soon as proof-of-concept experiments show efficacy. Smooth collaborative function of these three SIs will be ensured by appointment of a single overall coordinator.

Targeting of breeding efforts will be supported by value chain analyses produced in SI 1. Improved varieties that are the main SI 4 outputs will be rapidly provided to SI 2 and SI 3 for incorporation into crop management and cropping system research. New alleles for stress tolerance identified in SI 8 will be rapidly deployed in SI 4 breeding programs.

SI 4 will maintain a dynamic interface with SI 5 to provide capacity building in biosafety regulation and open-quarantine testing of transgenic materials. The two SIs will also jointly provide information exchange opportunities for national varietal release bodies on procedures that can accelerate the release and dissemination of useful germplasm.

What's new in this initiative?

- Drought tolerance breeding will be extended to Asia and Latin America, where the combination of increasing yields, climate change, and increasing costs of irrigation water will give rise to more frequent large-volume production shortfalls in maize and price variations that affect poor consumers.
- Breeding for waterlogging tolerance will be scaled up in Asia, particularly targeting areas receiving high rainfall in the monsoon season and prone to floods during crop growth and development.
- Screening under heat stress will be incorporated, based on recent studies of significant climate change-related impact in tropical maize, which may include heat-related impacts on flowering and grain filling (Lobell and Burke 2010).
- Screening for combinations of stresses—particularly drought plus heat and drought plus waterlogging—ill be initiated for the first time, because of the evidence that genotypes respond in a non-additive manner to combinations of stresses.
- A coordinated, inter-institutional biotic stress tolerance screening network will be established.
- A systematic public pipeline for marker development for biotic and abiotic stress tolerance genes will be implemented.
- Innovative seed production systems will be developed, allowing small-scale seed companies to produce hybrids at low cost without the need to produce large quantities of seeds of low-yielding and sensitive inbred lines.
- Innovative partnerships with multinational seed companies and emerging biotechnology capacities in China, India, and Mexico will be expanded to accelerate breeding gains for the benefit of the most disadvantaged countries and farmers, using both native and transgenic variation.
- Greater focus will be placed on the search for innovative approaches to speed the dissemination of drought-tolerant maize into areas with weaker seed value chains.

Targeting and impact estimates

Ten farming systems with greatest losses due to drought are included in this Initiative (Figure 5). La Rovere et al. (2010) estimated the impact of maize tolerant to drought and nitrogen stress in sub-Saharan Africa at 1.2 million tons annually after 10 years of research, assuming most likely rates of adoption and conservative yield improvements of 3–20%, depending on the site and seasonal conditions. Assuming proportional but delayed impact in Asia and Latin America (due to lack of previous research investments) and based on maize area affected by drought (PDII Index in Hyman's study ; Hyman et al. 2008) and doubling impacts for the period 2020–30 in Africa, this initiative would result in at least 1.7–4.5 million tons of additional grain valued at USD 280–815 million by 2020–30. La Rovere et al. (2010) indicated that a monetary benefit of an additional 50% would arise from reduced yield/price fluctuations, with a total producer benefit of USD 42–1,215 million by 2020–30.

Other issues

Gender

This strategic initiative is targeted at some of the poorest people in the developing world: smallholders who grow maize for subsistence in drought-prone environments, and who are unable to afford the tiny investment in fertilizer needed to improve their maize yields above the 1–2 tons per hectare level achievable without fertilizer in soils with low organic matter. Such farmers, primarily in sub-Saharan Africa, also usually have very little political influence and find it difficult to access input-subsidy programs. In general, women farmers in male-dominated households have primary responsibility for food crop production, while male household members invest their labor in more profitable cash-crop production or off-farm work. Women-headed households are usually poorer and less able to acquire inputs than households headed by males (Doss 1999).

Because inputs, particularly fertilizer, are allocated either to market-oriented crops or to individuals with political influence or high social standing, women farmers and women-headed households are disadvantaged in both respects. For example, in sub-Saharan Africa (SSA) women produce up to 80% of basic foodstuffs (including maize) both for household consumption and for sale. Yet, significant gender inequalities can be found in peoples' access to key productive assets and services: land, labor, financial services, water, rural infrastructure, technology, and other inputs, not only in SSA but also in Asia and Latin America. But, it is difficult to tell whether women grow lower-value subsistence crops because they have different preferences and concerns or because they cannot access the land, inputs, credit, information, and markets that would permit them to do otherwise (Doss 1999).

In Ghana, for instance, women farmers view maize production as a productive, income-generating activity yet refrain from growing maize because they lack the capital to purchase the required inputs (fertilizer, herbicide) and because maize cultivation is considered risky due to drought (Adjei-Nsiah et al. 2007). Because women farmers have little access to fertilizer inputs, varieties with improved low-N and drought stress tolerance offer a route to improved productivity. Women farmers and their dependants will therefore be among the principal beneficiaries of maize varieties with improved abiotic stress tolerance, assuming these are delivered in the form of low-cost, farmer producible OPVs or equitably distributed hybrid seed subsidies. Gender disaggregated farmer needs will be assessed as part of value chain analysis conducted in six regions and considered for germplasm development and distribution, with special emphasis on the effective targeting of women and young adult farmers by small- and medium-scale seed companies.

Capacity building

Effective managed stress screening is the key to successful abiotic/biotic stress tolerance breeding, but is difficult and requires detailed training. Training of NARS and private-sector breeders from target regions in the managed-stress breeding programs of CIMMYT, IITA and leading NARSs and private seed companies, through intensive short courses and longer-term work placements, will be the principal capacity-building activities of SI 4. Training materials, including detailed videos describing managed stress-screening techniques, will be made available via the SI 4 website and will be posted to widely used internet video file-sharing services. Training on breeding program information management will be conducted in collaboration with SI 5 and the Integrated Breeding Platform of the GCP.

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Strategic Initiative 5. Towards doubling maize productivity in the developing world

Value proposition

Through public–private partnerships, increase maize productivity among smallholders in high-potential areas of Asia, Africa, and Latin America, thereby providing food for 50–170 million poor maize consumers, reducing demands on land and irrigation, increasing the diversity of improved maize varieties grown by farmers and fostering a more competitive maize seed sector.

Estimated impact	2020	2030
Benefit to the poor	The target area includes an estimated 615 million maize-dependent poor	
Annual production increase	3.5 million tons maize grain	10.6 million tons maize grain
Food calorie equivalent (at 2,000 kcal)	9% of the caloric intake of 622 million maize consumers	28% of the caloric intake of 622 million maize consumers
Annual value addition	USD 575 million	USD 1,900 million
Benefit to the environment	Increased land and water use efficiency; increased deployment of maize genetic diversity	
Others	Strengthening of local entrepreneurs and innovators	

Justification

General background

Maize yields are much lower in the tropics than in the temperate regions, even in regions with adequate rainfall and where farmers can invest in yield-increasing inputs. Sustainably increasing maize farming productivity in favored regions without increasing environmental damage is critical to meeting the exploding demand for maize in the developing world. Achieving the required gains in productivity will require concerted scientific efforts to identify the most promising routes to increased yield and improved input use efficiency under tropical conditions, also to develop creative approaches that provide farmers with the tools they need to sustainably increase yields. The scientific program of this germplasm-focused SI will therefore seek to develop an improved physiological and genetic understanding of the factors determining yield potential in the tropics and subtropics, and then to incorporate this understanding into improved breeding approaches. Impact will be generated through innovative platforms that integrate public- and private-sector partners in germplasm development, testing, and dissemination.

The lack of access to seed of well-adapted maize hybrids is one of the major factors responsible for low maize yields in many area of the developing world with otherwise good production potential. CIMMYT and IITA have invested some effort to develop varieties and hybrids adapted to tropical and subtropical environments with high production potential, but this needs scaling-up and scaling-out. Scientists must expand breeding and testing in high-potential zones in developing countries to increase the rates of genetic gain and thus meet the exploding demand for feed and food grain. Simultaneously, the generally weak seed delivery mechanisms in such areas must be strengthened to ensure that improved seed and other relevant technologies reach the smallholders.

Progress to date and lessons learned

Although progress in breeding for yield potential under favorable conditions in the tropics has been substantial since CIMMYT and IITA initiated hybrid maize breeding around 1990, this major intitiative has never been comprehensively surveyed. Recent regional trials indicate that hybrid yield gains have been on the order of 1.0–1.5 t/ha during this period (CIMMYT, unpublished data), or approximately a 1%

gain per year. The physiological bases for these gains have not been studied and need to be understood if we are to improve on this rate of progress.

In temperate maize production it has been comprehensively demonstrated that the rapid yield gains from breeding over the last 50–60 years since the near-universal adoption of hybrids have resulted mainly from increases in plant density tolerance and from the broad-scale multilocation hybrid testing programs of commercial maize breeding companies that effectively sample conditions occurring in farmers' fields and that have contributed substantially to the development of resilient hybrids (Castleberry et al. 1984; Duvick and Cassman, 1999; Lee and Tollenaar, 2007). Much of this experience can be transferred to the tropics, but substantial differences also exist.

The use of hybrid seed is critical to the achievement of improved yield potential. However, small farmers, especially those who grow maize mainly for subsistence and market only part of their crop, are very sensitive to seed price. CIMMYT and IITA have learned important lessons about the delivery of low-cost hybrid seed to farmers in Africa through the DTMA project, which has as its goal the production and dissemination of 70,000 tons per year of drought-tolerant maize seed to the African smallholders.

Delivering low-cost hybrids to difficult-to-reach smallholders requires that local, small- and medium-scale seed enterprises (SMEs) be comprehensively supported with information on products, adequate and reliable supplies of foundation seed, training in seed production and seed business methods, and low-cost production systems. CIMMYT and IITA are pioneering innovative models for the integration of SMEs into consortia that can achieve the economies of scale in testing and germplasm development, thereby helping them to compete with global seed businesses. These platforms will allow the rapid delivery to small companies of tools hitherto available only to multinationals, including doubled haploids and marker-driven breeding systems (tools under development in SI 9). We are also validating innovative, low-cost hybrid seed production systems, including F2 x F2 crosses and crosses of advanced-cycle marker-assisted recurrent selection (MARS) populations.

Why international agricultural research?

Although private investments in maize breeding for subtropical and tropical areas have been increasing, they still comprise only about 5% of investments for temperate environments. Private sector investment in breeding programs for such areas is limited, because the financial and human resources are inadequate and because the farmers there do not represent an attractive market. As an example, most of the breeding investment in South Asia is targeted toward the profitable, irrigated winter maize sector, whereas 80% of all maize is grown under rainfed conditions in the summer, under higher disease pressure and risks of either drought or excess moisture.

There are also areas in the developing world where the private seed sector is underdeveloped due to high initial investment costs, lack of access to production credit or seed production and processing infrastructure, and weak extension systems unable to promote improved seed effectively to farmers. Farmers in these zones have no choice but to grow ill-adapted hybrids or recycled open-pollinated varieties (OPVs), and they tend to expand maize area to meet increasing local demand rather than look to increase yields. Undersupplied zones with good production potential are potential breadbaskets for local populations, and constitute potentially attractive markets for SMEs willing to serve smaller markets.

Publicly-funded NARSs alone have not adequately served the markets described above. Capital, financial, and human resources are often constrained in public research institutions. Moreover NARSs are often mandated to prioritize national food security above poverty alleviation, leading them to focus on commercial farms with the highest potential productivity. Both NARSs and SMEs rely on international centers to adapt germplasm for new environments, particularly where new traits and tools are required to bridge significant breeding gaps. CIMMYT and IITA are the sole global suppliers of elite (sub-)tropical maize germplasm free from intellectual property constraints. In collaboration with national research programs, the two centers have placed experienced breeders at strategic locations in important maize-producing nations—China, Colombia, Ethiopia, Kenya, India, Mexico, Nepal, Nigeria and Zimbabwe.

The centers have also established decentralized breeding networks that together exploit synergies of scale to develop elite inbred lines adapted to globally important tropical maize mega-environments (Annex 4). These networks draw on the wealth of genetic resources available through the Centers and on associated partnerships—including advanced public and private sector entities to access emerging breeding tools—to rapidly develop new inbreds that meet local demands.

Rapid-cycle marker-based breeding approaches have been designed (Heffner et al. 2009) and appear effective to increase rates of genetic gain (Eathington et al. 2007). Initial CIMMYT research has shown that low-cost approaches to produce double-cross hybrids from F2 x F2 crosses are feasible (CIMMYT, unpublished research). CIMMYT and IITA have also developed a range of topcross products involving crosses between OPVs and inbred lines or hybrids.

Faced with the urgent need to produce much more maize on less land, this SI will identify regions with the highest potential for productivity increases, and link with seed companies to define local germplasm needs, to enable pre-commercial, resource-poor farmers to boost their productivity and move from a subsistence to a commercial footing. In areas including sub-Saharan Africa, rainfed South and Southeast Asia, and Central America, where the private sector markets for hybrid maize are weak, we will work closely with other initiatives focusing on seed sector development.

Our aim is to support regional foundation seed production centers that can supply foundation seed of hybrid parents to emerging and existing SMEs. CIMMYT and IITA will provide parents of hybrids to the foundation seed production centers for multiplication and distribution to the SMEs and will also coordinate the formation of regional consortia of SMEs–to whom they will provide materials under development and with whom they will pool testing resources. An important initiative will involve training—staff of the companies will develop their skills in business management as well as in production and processing of good quality hybrid seeds and marketing them to farmers. This value proposition has a long-term exit strategy: it will have initial support from public funds, but as markets evolve the private sector can help defray the costs of technical support and partnerships.

Researchable issues

- Methods and models to define target areas according to their relevance to sustainable development, the environmental impact of enhanced maize production, and specific needs of resource-poor farmers.
- Introgression of traits and alleles necessary to sustain genetic gains in highly diverse tropical environments, in particular resistances to pests and diseases of increasing importance, along with fertilizer use efficiency, adaptation to acid soils, and tolerance to drought, heat, and waterlogging.
- Elucidation of traits associated with increased yield potential in the tropics through detailed physiological analysis and era studies.
- Design, validation, and implementation of innovative breeding strategies that sustain or increase rates of yield gain.

- Intellectual property management of open-source collaborative breeding and public germplasm deployment, so that resource-poor farmers gain access to affordable, high-quality seed of improved maize hybrids.
- The feasibility of alternative, low-cost hybrid seed production approaches.
- The impediments to the establishment and operation of viable seed companies in West Africa, Central America, and other under-served regions.
- Seed trade in West Africa, Central America and other under-served regions (a comprehensive study is needed).

Outputs

1. Socioeconomic and GIS-based information on resource-poor farmers' needs and on areas with high potential for productivity increases.
    - GIS-based delineation of Asian, Latin American and African target environments with high production potential, or where productivity is limited by one main, correctable or avoidable factor (for example, soil acidity).
    - Value-chain and market analyses to guide research investments and identify key traits required by farmers and end-users.
2. Formal International Maize Improvement Consortium (IMIC) whose outputs include:
    - Prioritization of needs and products for local and regional seed companies, farmers, and NARSs.
    - Elite maize germplasm, developed through Consortium-managed, flexible "open-source" breeding networks involving committed research partners targeting similar needs, similar agroecologies, or similar mega-environments based on needs prioritized by IMIC members.
    - Web-based publication of critical performance data for research products obtained through collaborative testing.
    - Efficient breeding programs through rapid and effective application of new tools, such as genomic selection and doubled-haploids.
3. Foundation seed production units delivering enough foundation seed to permit rapid production scale-up of new hybrid production by small companies in sub-Saharan Africa and Central America.
4. A web-based platform for development partners' feedback and for management of germplasm information and shipments.
5. A set of decentralized phenotyping sites managed by research partners (including CIMMYT, IITA, national programs, and private companies) to characterize and improve germplasm for prioritized traits.
6. Improved physiological understanding of factors affecting yield potential and input-use efficiency in tropical maize under favorable production conditions—including density tolerance, maintenance of canopy function, and biomass partitioning.
7. A freely-available supply of characterized and diverse public maize inbreds (donors and elite lines) supporting a competitive seed industry and seed self-sufficiency in participating countries.
8. A stream of unique doubled-haploid lines, pre-selected on the basis of genotype, delivered to seed companies on a cost-recovery basis, allowing them to develop proprietary products.
9. Low-cost hybrid seed production approaches (F2 x F2 double crosses, topcrosses, varietal crosses, and population crosses of MARS products) validated and shared with partners.
10. Enhanced capacity of breeding programs and seed producers through demand-driven training, for developing, identifying, and delivering locally adapted maize hybrids to emerging markets and resource-poor farmers.
11. Molecular markers for key adaptive, oligogenic traits for use by national research systems, seed companies, and commercial service providers.

12. Foundation seed production units in cooperation with NARSs and SMEs in Latin America, sub-Saharan Africa, South Asia, and Southeast Asia for a consistent local source for breeding lines.

Research and development partners

Research collaboration will be formalized with partners that are able and willing to engage in high-quality collaborative phenotyping and open-source breeding. CIMMYT and IITA have collaborative germplasm development with diverse national research systems and private sector partners in Africa, Latin America, and Asia. Using a competitive approach, this network will be strengthened and performance contracts developed with public and private organizations that can provide rapid return of high-quality data or contribute to open-source breeding and have effective germplasm import/export approaches.

Development partners will include formalized members of an International Maize Improvement Consortium (IMIC) from national research systems, the private sector, and non-governmental organizations. Members will influence breeding priorities and get rapid and (in some instances) preferential access to resulting germplasm, training, and outputs from other MAIZE initiatives, in particular crop management innovations. Membership will imply a distinct set of obligations, including return of information on germplasm performance and use. Non-members will get access to a more limited set of germplasm as international public goods.

Outcomes

- The public and private sector seed industries will provide low-cost seed of diverse and highly-productive maize hybrids to farmers who are in transition from subsistence or semi-commercial footing to commercial production.
- Smallholder farmers will increase their production, improve their livelihoods, and will have less need to encroach into forests or use hill slopes for maize production.
- A diversifying seed industry in developing countries will provide employment opportunities and give rise to innovations.
- National research systems and seed companies will participate in research consortia that empower them to establish and implement an effective collaborative research agenda, including use of new research tools and information.

Key milestones

2010: Collaborative development of business plans, terms of interaction with research for development partners, and refined specification of germplasm requirements.

2011: International Maize Improvement Consortium (IMIC) established in Asia, Africa, and Latin America and web platform established.

2011: Geographic information systems and client feedback used to better define undersupplied markets and relative priorities.

2011: Impediments to the establishment and operation of viable seed companies in West Africa identified and results published and disseminated.

2012: Screening sites chosen for the IMIC phenotyping consortium; performance contracts formalized with reliable research partners for the 20 most important traits worldwide, selected from among:

- *Abiotic stress tolerance traits:* Drought, low nitrogen, low pH, aluminum toxicity, heat and waterlogging.
- *Biotic stress resistance traits:* Distinct traits for resistance to diseases, parasitic weeds and insect pests.
- *Mega-environment adaptation:* Maturity and yield potential in six mega-environments.

- *Other producer- or consumer-relevant traits:* Seed yield, grain characteristics, and composition, lodging, and food and feed values.
  The biotic/abiotic stress tolerance work as listed above will be undertaken in dynamic interface with SI 4.

2012: Socioeconomic framework developed for effective gender-disaggregated market analysis and improved targeting and feedback.
2012: Framework for managing open-source collaborative breeding plans and IP issues finalized to maximize farmers' access to affordable, quality seed.
2012 Framework for alternative business plan models for foundation seed units elaborated for Africa, Asia, and Latin America, and seed production initiated.
2012: A comprehensive study on regional seed trade in West Africa completed, results published, and a regional policy workshop held to discuss the findings and chart the way forward.
2013: Unique doubled haploid line sets delivered to IMIC members annually from 2013 onward.
2014: Complete set of managed-stress screening systems implemented and validated.
2014: Reliable markers for key oligogenic biotic stress tolerance alleles (MSV, CSC, GLS) and soil acidity available for use by breeders.
2015: Acid-, waterlogging- and heat-tolerant hybrids in advanced validation/PVS testing.
2016: Progress from three cycles of MARS and genomic selection evaluated.
2016: Genes with large effects on waterlogging and heat tolerance fine-mapped.

Annual milestones

- Joint evaluation of at least 100 new hybrids or OPVs by IMIC members and NARS partners.
- Release and commercialization of at least two new hybrids per region annually after 2012.

Linkages with other SIs

SI 5 has a strong emphasis on cash grain production in more favorable environments, but will be closely coordinated with SI 4, and will make use of abiotic/biotic stress tolerance/resistance donors and genes identified in that initiative. SI 5 will have a stronger regional focus in Asia and Latin America, but will also serve high-potential areas in Africa, particularly the Eastern African Highlands. Germplasm products of SI 5 will feed into SI 2 and SI 3 for wide-scale on-farm testing and development of hybrid-specific management recommendations.

If SI 5 is to deliver on its promise of increased rates of genetic gains, it is crucial that improved breeding technologies be implemented in the CIMMYT and IITA breeding programs and shared with national and regional partners as soon as possible. Tools developed in SI 9 will be implemented as soon as proof-of-concept experiments show efficacy. New alleles for stress tolerance identified in SI 8 will be rapidly deployed in the SI 5 breeding programs.

SI 5 will collaborate with SI 4 and SI 9 to provide capacity building in biosafety regulation and open-quarantine testing of transgenic materials. The two SIs will also jointly provide information exchange opportunities for national varietal release bodies on procedures that can accelerate the release and dissemination of useful germplasm.

Targeting of breeding efforts will be supported by GIS assessments of potential productivity and by value chain analyses produced in SI 1.

What's new in this initiative?

- The initiative provides a demand-driven approach that will lead international public maize germplasm development into the future. It uses membership for research and deployment, and performance contracts to improve focus, research quality, and delivery to a clear target group of "pre-commercial" smallholders. In collaboration with APAARI members, CIMMYT successfully developed and launched the Asian Hybrid Maize Consortium in 2010, and many aspects of this initiative have been sounded out with interested members and other partners internationally.
- Low-cost seed production, including scaled up provision of breeder seed and use of innovative variety types, will be systematically addressed.
- Traits associated with high yield potential and efficient input use in tropical environments will be intensively studied for the first time through detailed crop physiological analysis and era hybrid studies.
- State-of-the-art tools (doubled haploids, high-density marker-based genomic selection) will be applied to the improvement of yield potential and stress tolerance in higher-rainfall environments.
- The initiative formalizes intellectual property (IP) boundaries on research collaboration between CIMMYT, IITA, national research systems and seed companies, for equitable research contributions; each research partner can use germplasm for further development while the jointly developed germplasm remains in the international domain.
- CRP-level investment, as compared to fragmented short-term funding of individual donors, enables such an initiative for the first time and will significantly boost research efficiency and benefit more farmers.

Targets and impact estimates

The targeted farming systems are selected on the basis of current importance of rainfed maize and poverty, projected demand increase, and potential to increase rainfed productivity. These regions mainly include areas with growing-season rainfall above 700 mm and a proportion of maize area above 10%, but could include areas with less than 10% maize where soil acidity problems could be addressed through genetic approaches. Breeding targets within the farming systems identified in Figure 5 will be based around the six maize mega-environments that enable effective use of international collaboration for targeting local needs (Figure 7). Assuming that within 10–20 years local seed companies can increase current seed adoption from an average of 36% to 40–50% using germplasm developed through this initiative, an area of 3.5–10.6 million hectares would be reached with hybrid seed, producing at least 3.5–10.6 million tons of additional grain valued at USD 575–1,900 million by 2020–30.

Other issues

Gender

Gender-specific variety needs will be assessed in market surveys and considered during germplasm development. Gender analysis will be a component of seed system studies to permit development of strategies that ensure women farmers have unimpeded access to improved, high-potential germplasm. Capacity building and seed business support programs will give preferential access to women participants.

Gender may influence the decision to cultivate not only different crops but also different varieties of the same crop. Maize, for instance, may be grown as a cash or subsistence crop. High-yielding maize varieties were introduced in many areas to generate a marketable surplus, but many of these varieties had processing, cooking, and storage characteristics different from those of local varieties. The high-yielding varieties were often promoted as cash crops. Consequently in many places local varieties are considered “women’s” crops, and high-yielding varieties are considered “men’s” crops (Badstue et al. 2007).

To the extent that high-yielding varieties are grown for cash and local varieties for food, this gender-variety pattern may persist. However, as high-yielding varieties that meet the consumption preferences of smallholder farmers are developed, the distinctions between subsistence and cash varieties may become blurred. For instance, both hybrid maize and local maize can be viewed as either subsistence or cash crops, depending on a farmer’s circumstances and market opportunities.

Capacity building

Increasing the effectiveness of breeding and seed production in high-potential environments will require close partnership with highly-skilled national and regional scientists and seed producers. Training of NARS and private-sector breeders and seed production managers from target regions in the breeding programs of CIMMYT, IITA, and leading NARS and private seed companies, through intensive short courses and longer-term work placements, graduate training, and post-graduate study periods, will be the principal capacity-building activities of SI 5. Substantial investments in breeder training course development and in seed business management training have already been made in several CIMMYT and IITA projects—notably DTMA—and will be made more broadly relevant and accessible in SI 5.

Training materials, including highly detailed videos describing conventional and novel seed production techniques, will be made available via the SI 5 website and will be posted to widely-used internet video file-sharing services. Training on breeding program information management will be conducted in collaboration with SI 4, SI 9, and the Integrated Breeding Platform of the Generation Challenge Program.

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Strategic Initiative 6. Integrated post-harvest management to improve maize food security and safety

Value proposition

Improve the food security and safety, health, and marketing options of some 6 million smallholders in 15 countries of Africa, Asia, and Latin America by reducing post-harvest losses and mycotoxin contamination in maize-derived foods.

Estimated impact	2020	2030
Potential food security impact	Approx. 180 million poor people, in countries where maize contributes on average 30% of total calories and protein.	
Smallholder families potentially gaining from this initiative	2 million	6 million
Other benefits	Reduced losses in storage, increased income generation, and reduced health risks/burden through foods free of mycotoxins and insect pest wastes.	
Reduction of post-harvest losses (%)	20	25
Value of saved grain	USD 200 million	USD 650 million

Justification

General background

Safe storage of maize at the farm level is crucial, as it directly impacts on poverty alleviation, food and income security, and prosperity for smallholder farmers. Without appropriate grain storage technologies, farmers are forced to sell maize when prices are low to avoid post-harvest losses (PHLs) from storage pests and diseases. They cannot add value to maximize gains from their harvest, nor use their harvest as collateral to access credit. Ultimately their food security is undermined.

Food security and safe storage at the farmer level go hand-in-hand. As well as providing food security for times of scarcity, effective grain storage is an inflation-proof savings bank; grain can be cashed as needed or used directly as a medium of exchange (i.e. in payment for work such as field clearing and weeding). Stored grain is also needed for farm-level enterprises such as poultry production, beer brewing, and cooking foods for sale. Appropriate low-cost storage technologies and high-yielding maize varieties resistant to storage pests and diseases must be made readily available to farmers, so they can safely store and maintain quality of their produce.

PHLs result from infection by microorganisms and infestation by insects and rodents. They can be quantitative or physical, resulting in weight loss of the product. They can also be qualitative—that is, reflecting changes in appearance, taste and texture, or in nutritional and economic value. Most importantly, post-harvest damage affects food safety, harming the health, wellbeing, and productivity of consumers and increasing societal health costs. PHLs also result in lost market opportunities and resources (waste of land, labour, inputs, and soil fertility). Therefore, reducing losses during and after harvest can significantly contribute to food security and safety.

Storage insect pests, mainly the maize weevil (*Sitophilus zeamais*), larger grain borer (LGB—*Prostephanus truncatus*), angoumois grain moth (*Sitotroga cereallela*) and the lesser grain weevil (*Sitophilus oryzae*), cause an estimated 20–30% loss of maize, with consequent impact on food security and income generation. Ear and kernel rots of maize, caused by a variety of fungi, are prevalent in warm, humid, tropical and subtropical maize growing environments. About 56% of area under maize in subtropical, mid-altitude, transition zone and highlands experience economic losses due to ear rots, and up to 44% of maize grown in tropical lowlands is lost to ear rots. Economic losses result from reduced grain quality and mycotoxin contamination—especially aflatoxin and fumonisin (produced by *Aspergillus flavus* and *Fusarium verticillioides* respectively)—making grain unsafe for food or animal feed.

Mycotoxin contamination is a serious problem that has a long-term detriment on human and animal health and is an obstacle to developing trade and export markets. Sub-lethal exposures to aflatoxin suppress the immune system, increase the incidence and severity of infectious diseases, retard child growth and development, and reduce the efficacy of vaccination programs (Williams et al. 2004). Consumption of high doses of aflatoxin leads to aflatoxicosis, causing acute illness and even death. In 2004 more than 125 people died in Kenya from eating maize with aflatoxin B1 concentrations as high as 4,400 parts per billion (ppb)—220 times the Kenyan limit for foods (Lewis et al. 2005).

Commercial food and feed sectors, large institutional buyers such as the World Food Program, and national food reserve agencies require mycotoxin-safe maize. Mycotoxin-contaminated products are rejected or fetch lower prices. Without effective management of mycotoxins, farmers cannot participate in grain markets nor enjoy the economic benefits of increased domestic, regional, and international trade.

The extent of mycotoxin contamination of maize in many developing countries is poorly understood. Additional data on mycotoxin distribution and severity are required to better assess the importance of mycotoxins and identify critical points along the maize value chain where intervention technologies are most likely to have the greatest impact. Mycotoxin awareness and technical innovations supported by enabling policies and supportive institutions are critical for reducing mycotoxin exposure (Leslie et al. 2008). Mycotoxin contamination is invisible, therefore farmers, traders, processors, and consumers are frequently unaware of the problem or the related health risks. Low-cost, rapid assaying tools (Berardo et al. 2005), low-cost, effective storage interventions (like metal silos, super grain bags) and insect-pest/pathogen-resistant maize germplasm are all needed, and must be developed and made available to users (Abebe et al. 2009; Bergvinson and Garcia-Lara 2004; Hell et al. 2008; Menkir et al. 2008).

Why international agricultural research?

CIMMYT has developed efficient tools to screen maize genotypes for resistance to storage insect-pests and has identified maize germplasm that can reduce post-harvest losses by 30–50% (Garcia-Lara et al. 2007, 2009; Likhayo et al. 2008; Mugo et a. 2010; Tefera et al. 2010a,b). CIMMYT and IITA have developed tools to screen for resistance to ear rots, mycotoxin production, and have resistant inbred lines. Both centers maintain genetically diverse maize collections, providing an invaluable source of resistance. They also operate global and regional maize testing networks and have excellent links with private seed sectors and non-governmental organizations to promote seed production and dissemination.

Mycotoxin-related food safety and market effects are almost always multi-faceted and too complex to be addressed by the research system of any single developing country. CIMMYT is currently involved in five major initiatives to address post-harvest losses and mycotoxin contamination:

1. The initiative "Developing maize resistant to stem borer and storage insect pests for eastern and southern Africa—IRMA III Conventional (2009–2013) " funded by the Syngenta Foundation for Sustainable Agriculture is a comprehensive breeding, capacity-building and seed-production effort targeting eight countries.

2. The project "Effective grain storage for better livelihoods of African farmers" funded by the Swiss Agency for Development and Cooperation is validating grain-storage methods in eastern and southern Africa.
3. The project "Exploring the scope of cost-effective aflatoxin risk reduction strategies in maize and groundnut value chains so as to improve market access of the poor in Africa" funded by the Bill & Melinda Gates Foundation aims to increase knowledge and awareness and identify methods and technologies for reducing aflatoxin contamination.
4. The project “Developing and validating drought-tolerant maize to stabilize productivity and reduce mycotoxin contamination resulting from climate change” funded by FONTAGRO is developing maize varieties/hybrids that combine drought tolerance, resistance to ear mold fungi and reduced mycotoxin contamination.
5. The project “Validation of *super bags* as a low-cost technology for managing storage insect pests and fungi” funded by Mexico's Ministry of Agriculture (SAGARPA) is validating the efficacy and suitability of hermetically sealed plastic bags to manage storage pests of maize and minimize mycotoxin contamination.

In addition, CIMMYT has adopted the low-cost ELISA technology to detect and quantify grain aflatoxin and fumonisin content; it uses ELISA as a tool in breeding programs that aim to develop host plant resistance to mycotoxin contamination.

For more than 15 years IITA has employed diverse approaches for mycotoxin control with multiple research-for-development partners. Research topics have included: host plant resistance (funded by USAID & USDA-Foreign Agriculture Service); management and bio-control (funded by the Austrian Development Agency); management, bio-control, and modeling (funded by AATF and the European Union); linkages between climate change, aflatoxin contamination and health (as part of the Agriculture and Health Research Platform); biocontrol (the Government of Senegal); aflatoxin and trade-related issues (WTO-STDF).

CIMMYT has worked in partnership with various institutions to undertake strategic research and germplasm development for post-harvest insect-pest-resistant maize. The Center has developed low-cost methodologies/protocols for screening for post-harvest resistance and also developed and released germplasm products with 30–50% resistance to *P. truncatus* and *S. zeamais*. It is now validating the use of super bag technology and metal silos for safer grain storage; another advance is the development of techniques for drying grain in humid environments (Mugo et al. 2010; Tefera et al. 2010 a, b).

As well as progressing with all the above initiatives, CIMMYT is using the doubled haploid technology to rapidly develop maize lines combining resistance to ear molds and mycotoxin production, insect resistance, and drought tolerance, thereby reducing stress on the plant and minimizing infection and mycotoxin contamination of maize.

IITA’s research-for-development focuses on mycotoxin management practices. Its program has resulted in a good knowledge base, new technologies and better policies to minimize aflatoxin contamination. IITA has analysed how aflatoxins impact on child health and also undertaken a food basket survey, bio-ecology studies of aflatoxin and fumonisin production, and biological control through a competitive exclusion strategy. Other studies include resistance breeding, development of a low-cost quantitative method for aflatoxin analysis, and research on the impact of climate change on aflatoxin. The research team has disseminated several pre- and post-harvest strategies and also conducted public awareness campaigns regarding aflatoxin contamination in West Africa. Efforts are underway to augment mycotoxin monitoring capacity of regulatory agencies and the private sector, and to add further value by linking farmers producing mycotoxin-safe maize with markets.

Lessons learned, challenges to progress, and strategies for success
Significant progress has been made in identifying resistance to ear mold fungus, storage insect pests and mycotoxin reduction, and tolerance to drought. However, resistance and/or tolerance to these traits is quantitative and controlled by many genes with small effects (quantitative trait loci—QTL) that are influenced by the environment. Therefore, progress towards development of varieties/hybrids with high levels of genetic resistance has been difficult to achieve (Munkvold 2003). This is because breeding strategies to select for preferred genetic traits (resistance to insects and ear mold) are plagued by many hurdles including: inconsistent, labor-intensive inoculation techniques (Campbell and White 1994); lack of single genes and resistant control genotypes; the cost of evaluating large numbers of progeny, especially for mycotoxins (Munkvold 2003). Identification of QTL with large effects and development of gene-based markers will help circumvent some of these problems and significantly assist product development. More highly polygenic forms of resistance will require improved predictions of breeding value using high-density genomic selection approaches.

Traditionally, breeding programs have used resistance to ear mold as an indication of reduced mycotoxin accumulation, but a growing body of research is revealing that resistance to ear rots might not be a very good indicator of resistance to mycotoxin accumulation. QTL mapping is revealing that the two traits might be under distinct genetic control (Busboom and White 2004; Wisser et al. 2006). The lack of a cost-effective mycotoxin assaying tool for routine use in breeding programs has slowed development of resistant germplasm. However, ICRISAT and IITA have recently developed an ELISA-based mycotoxin assaying system that reduces the cost of mycotoxin detection and quantification from approximately USD 15.00 to about USD 1.00 per sample, making it feasible to implement mycotoxin assaying in regular breeding programs.

Plant stress predisposes maize kernels to colonization and infection by ear rot fungi. High aflatoxin levels are often associated with abiotic stresses such as drought, heat, and nitrogen-deficient soils, also with tillage operations and with biotic stresses such as insects, diseases, and weeds (Moreno and Kang 1999). A strategy to minimize stress to the plant will significantly reduce infection by ear mold fungi and subsequent mycotoxin accumulation. Sources of resistance or tolerance to the different stress-inducing factors have been identified and some are now available in elite germplasm. The challenge is to combine the different traits in the same background and test their performance to manage storage insect pests and minimize mycotoxin accumulation. The doubled haploid technique now being used in CIMMYT will help rapidly develop lines containing a combination of alleles favorable to different stress factors.

Apart from reducing yield and quality, storage insect pests serve as vectors for grain storage molds, creating wounds that serve as entry points for the fungus and through respiration, conditions conducive to fungal growth. CIMMYT has developed cheap technologies to select for resistance to post-harvest insect pests and has identified then transferred into elite lines resistance to storage pests. Doubled haploid technology will be used to combine resistance to storage fungi and insects, so as to minimize post-harvest losses.

Adequate storage facilities are essential to preserve quality, minimize storage losses, and maintain food safety for food security. Although substantial research-for-development efforts have gone into storage, there have been many cases where small-scale farmers have not taken up the improved storage technologies —sometimes the technologies turn out to be inappropriate for farmer needs, and they may not be available at the right price or the right time *(*Compton et al. 1993*).* CIMMYT is using participatory approaches to validate several low-cost technologies (metal silos, hermetically sealed plastic bags, use of chemicals) to manage maize storage pests under farmer conditions and in different environments, while also creating technology awareness among farmers. Once validated, useful technologies will be scaled up and out to reach as many small farmers as possible, and providers or manufacturers of these technologies would be identified. The challenge is to have the products delivered in a cost-effective way so that all farmers have access.

Work by IITA has shown that 99% of children at weaning age in Benin and Togo are highly-exposed to aflatoxin health risks that stunt their development. Several pre- and post-harvest strategies have been tested and disseminated to reduce risk of aflatoxin and fumonisin contamination. Researachers continue to investigate strategies to reduce impact on trade, to introduce biological control and to develop resistant cultivars using novel approaches. Public awareness campaigns with governmental organizations seek to increase trader and consumer awareness of the deleterious nature of aflatoxin contamination.

Training of students and national program staff and buy-in from policy makers and grass-root-level organizations is a powerful model for institutionalizing PHL and mycotoxin management in any country. An integrated partnership and networking between IITA, CIMMYT, NARSs and other partners are the key elements for success.

Factors limiting progress

1. The lack of adequate and sustained funding is leading to loss of expertise in the CG centers and NARS partners, and halting impetus in key research areas.
2. The lack of adequate linkage between the agriculture and health sectors has kept policy makers from organizing a coordinated effort.
3. Mycotoxins cannot be seen, so people are often not aware of their presence or the dangers of marketing or eating contaminated food. Farmers are more responsive to things they can see, and the lack of a cheap and robust mycotoxin assaying tool for the field hinders their awareness.

Researchable issues

- The magnitude and impact of post-harvest grain losses from insect pests and pathogens in maize; risks from mycotoxin contamination, including potential effects from climate change.
- Low-cost technological interventions to mitigate post-harvest losses and mycotoxin contamination; development, testing, dissemination.
- Tools and protocols to effectively screen germplasm against post-harvest insects, fungi, and mycotoxins.
- Physiological and genetic bases of resistance and germplasm with resistance to major post-harvest pests and pathogens.
- Procedures to minimize exposure of high-risk populations to aflatoxins and reduce the flow of contaminated grain to alternative markets.
- Impacts of improved post-harvest technologies.

Outputs

1. Documented knowledge of the magnitude and impact of post-harvest grain losses, mycotoxin contamination, risk maps, and prediction tools for target regions.
2. Strategies designed for appropriate interventions.
3. Promising post-harvest storage technologies identified and tested.

4. Hubs and protocols to phenotype and assay for mycotoxins developed.
5. Genetics and mechanisms of resistance to post-harvest pests and diseases identified.
6. Molecular genetic stocks/tools (genes, QTLs, molecular markers, and resistant donors) developed, validated, and ready for use in breeding programs.
7. Resistant germplasm (inbred lines, OPVs, hybrids) developed, tested, and disseminated in target countries.
8. Alternative mycotoxin-reducing technologies (including biological control of aflatoxins) validated and promoted.
9. A publicly accessible database on mycotoxins and relevant technological interventions (seed health, drying, handling, treatments and processing for improving post-harvest storage) developed and available.
10. The technical capacity of research collaborators, farmers, and others in the value chain enhanced for overall integrated management of post-harvest insect-pests and pathogens; awareness created among stakeholders on health risks of mycotoxin.
11. Ex-post impact assessment studies published and disseminated.

Research and development partners
CG centers (CIMMYT, IITA, ICRISAT, IFPRI); advanced research institutes (Max Planck Institute for Molecular Plant Physiology; CINVESTAV-Mexico); national research systems in target countries; seed, chemical and food-processing companies; universities in the USA and Mexico (Texas A&M, Tecnológico de Monterrey); USDA-ARS.

National research and extension systems, grain dealers, private seed sector and traders; non-governmental, community-based and farmer organizations; regulatory authorities; World Food Program, WHO, FAO, KEMRI/CDC (Kenya), NAFDAC (Nigeria), and the Millennium Village Project (Nigeria).

Outcomes
- Low-cost mycotoxin screening assays used on a routine basis, and low-cost safe storage facilities adopted by at least 20% of smallholder farmers.
- Farmers and consumers in high-risk target regions gain knowledge and become aware of mycotoxins and associated health risks, and methodologies/technologies for minimizing contamination.
- A minimum of five seed companies and five community-based seed producers market maize varieties resistant to storage pests and ear molds that have reduced mycotoxin production.
- Farmers who practice aflatoxin biocontrol and other management practices reduce aflatoxin concentration by at least 50%.

Key milestones
2011: Local post-harvest storage and handling practices identified and gaps (needs) established; post-harvest networks set up in each target country.
2012: Extent and intensity of post-harvest losses and mycotoxin contamination along maize value chains determined; an aflatoxin biocontrol product registered in Nigeria.
2011–15: Germplasm with resistance to insect pests and ear mold fungi, and with reduced mycotoxin accumulation identified and used as donors to develop elite, locally adapted inbred lines.
2013: The effectiveness of low-cost storage technologies is validated; post-harvest insect pests/pathogens screening hubs established.
2014: High-throughput and low-cost mycotoxin screening method developed and implemented and stakeholders trained.

2015: At least 10 new inbred lines and 20 new hybrids/OPVs with resistance to post-harvest insect-pests/pathogens developed and made available for use by partners; markers/genes/QTL for resistance to post-harvest insect-pest/pathogen detected and validated.

2016: A publicly-accessible database on post-harvest insect pests, losses, extent of mycotoxin contamination and relevant technological interventions developed and made available to partners.

2013–16: At least 80,000 people in target countries informed about mycotoxin-associated health risks, low-cost storage structures, mycotoxin-assaying methodologies and management strategies.

2016: Ex-post assessment undertaken to gauge the impact of improved storage technologies on the livelihoods of adopting farmers.

Linkages with other SIs

SI 6 will use high-potential, stress-tolerant germplasm developed in SI 4 and SI 5 as parental materials for introgression of genes affecting mycotoxin contamination, and will deliver tolerant donors for use in these SIs. SI 6 will use new tools developed in SI 9 (particularly doubled haploids) to speed line extraction, and introduce rapid-cycle genomic selection to speed population improvement for highly quantitative traits such as storage insect resistance.

What's new in this initiative?

- The SI will take a mulitfaceted approach— advanced breeding tools (including doubled haploids and markers) will develop germplasm that combines resistance to post-harvest insect pests, ear molds, drought and mycotoxin contamination, and this will be coupled with introduction of low-cost storage structures and mycotoxin assaying techniques to limit post-harvest losses and mycotoxin-related health risks. Biocontrol would be a new tool for aflatoxin mitigation in Africa.
- The SI shall aggressively tackle the problems of scaling up low-cost storage structures and screening assays, also lift awareness of problems and thus mitigate post-harvest losses and health risks and burdens from mycotoxin contamination. Safe storage of maize at the farm level is crucial, as it directly impacts poverty alleviation, food and income security, and prosperity for smallholder farmers.
- Megaprogram-level investment provides the long-term focus needed to effectively address the complex problems of PHL and mycotoxin contamination for maize.

Targets and impact estimates

Primary targets for this SI will be maize-based farming systems in five countries of sub-Saharan Africa (Kenya, Malawi, Nigeria, Uganda and Ghana), two countries in Asia (Indonesia and Nepal), and Mexico. In all these countries maize yields are low relative to worldwide averages and crops suffer high levels of mycotoxin contamination, with more than 15% of grain lost during storage.

	Kenya	Malawi	Nigeria	Uganda	Ghana	Indonesia	Nepal	Mexico
Production (tons)	2,367,237	3,444,655	7,525,000	1,266,000	1,100,000	17,659,067	1,878,648	24,320,100
Grain loss (%)	20–25	20–25	5–10	20–25	5–10	6–17	4–22	10–25
Mycotoxin incidences (%)	25–30%; > 20 ppb	9% > 20 ppb	27% > 20 ppb	30% > 20 ppb;	65–80%; 30-2000 ppb	47%; >50 ppb	50–83% >50 ppb	20–89%; >20 ppb
No. of poor (in millions, under USD 1)	9.0	5.9	107.1	7.8	10.7	18.2	10.4	10.9

Assuming that low-cost storage facilities and resistant maize germplasm are disseminated to at least 2–6 million smallholders in the target countries, and post-harvest losses and mycotoxin contamination are reduced by 20%, this has an annual value of USD 200 million by 2020 and USD 650 million by 2030.

Technology dissemination and up-scaling timelines of available technologies.

Time line	Low-cost post-harvest technologies		Germplasm	
	Storage structures	Mycotoxin assaying	Insect-resistant germplasm	Mycotoxin-resistant germplasm
2011	Post-harvest networks set up and low-cost storage technologies validated in at least 50 on-farm and on-station sites per target country	Centralized screening facilities established at strategic locations to implement the research agenda	Variety releases in two countries	On-station validation of potential sources of resistance (one site in each target country)
2012	At least 100 on-farm validation sites per target country	At least 1,000 samples assayed for key mycotoxins (aflatoxin and fumonisin)	Variety releases in an additional three countries	Re-validation of sources of resistance: at least one site per target country
2013	At least 500 on-farm sites established per target country	At least two new laboratories established to decentralize testing; partners trained and at least 5,000 samples tested for key mycotoxins	Foundation seed production (2 tons) and links established with private seed companies	Identified sources of resistance used to develop segregating populations for mycotoxin resistance
2014	At least a 1,000 on-farm sites established; links established with manufacturers of storage structures	At least two new laboratories established, depending on accessibility and demand; at least 5,000 samples assayed for mycotoxins	At least 50 tons of insect-resistant OPVs/hybrids produced	Development of mycotoxin-resistant lines (using DH technology). Strategy is to combine traits that contribute to reduced mycotoxin accumulation.
2015	At least 1% of smallholder farmers are using low-cost storage structures	Maize from at least 1% farmers is being assayed for key mycotoxins	At least 200 tons of insect resistant OPVs/hybrids produced	Development and test crossing of mycotoxin-resistant lines and different environments known to influence infection and contamination
2016	At least 5% of smallholder farmers are using low-cost storage structures	Maize from at least 5% of farmers is being assayed for mycotoxins	At least 500 tons of insect-resistant OPVs/hybrids produced	On-station testing of hybrid (at least two sites per target country)

Other issues

Gender

In developing countries, women play major roles in maize production, storage, processing and food preparation. This initiative will specifically target women for food safety and security. Women usually sort and take away the highly contaminated culls for home consumption. Development of methods to divert the contaminated component would reduce mycotoxin exposure in women and children.

Capacity building
SI 6 will build capacity in PHL prevention, mycotoxin assaying, and use of breeding to address PHL and mycotoxin contamination; this will take place through short courses provided for breeders, analytical service providers and extension leaders. The research capacity of NARS and private sector scientists will be built through training visits and through in-depth incorporation into SI 6 research of NARS and private-sector scientists as graduate students and post-doctoral fellows.

Special efforts will be devoted to the development of high-quality, web-based information products (videos, web-based courses), to the design and use of low-cost storage technologies, and to building awareness of the health consequences of consuming mycotoxin-contaminated grain.

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Strategic Initiative 7. Nutritious maize

Value proposition
Using native maize genetic diversity and novel tools, develop and disseminate maize varieties that are biofortified for pro-vitamin A (pro-V A), zinc, or essential amino acids (quality protein maize—QPM), thereby reducing 10–20% of the life-years that are lost annually to Vitamin A deficiency in five sub-Saharan African countries alone, and benefiting malnourished children who grow up on maize-based diets.

Estimated impact	2020	2030
Smallholder families potentially gaining from this initiative	200,000 (VA: 40,000; QPM: 160,000)	500,000 (VA: 150,000; QPM: 350,000)
Increase in maize production	52,000 tons	130,000 tons
Value of nutritionally enriched maize in terms of disability adjusted life years (DALYs)	>200 million USD (2 million DALYs at $100 = $200 million; 52,000–130,000 tons of maize at $200/ton = 10.4—$26 million); This benefit is far higher than the cost of breeding, testing and disseminating nutritionally enriched maize (Bouis and Welch 2010)	
Increased human productivity (%)	Between 0.5 and 1% of the national human productivity is lost due only to VA deficiency each year in five representative African countries; 10–20% of this is expected to be recovered as an impact of this project.	

Justification
General background
Maize is the staple food of hundreds of millions of people in tropical and subtropical areas of the developing world. In Mesoamerica, annual maize consumption exceeds 80 kg per capita in Guatemala, Honduras, and El Salvador, rising to 125 kg in Mexico. Maize is also the most important cereal food crop in sub-Saharan Africa (SSA), where consumption levels exceed 130 kg per capita per year in Lesotho, Malawi, and Zambia (FAOSTAT 2006, 2003–2005 average). Maize is mainly a source of energy, providing over 20% of total calories in human diets in 21 countries, and over 30% in 12 countries that are home to a total of more than 310 million people. In South and Southeast Asia, where direct maize consumption on an annual average is estimated to be only 6 and 16 kg per capita, respectively, but there are several areas (especially in the highlands and tribal regions) where maize is consumed directly at much higher rates. Heavily maize-based diets tend to be deficient in the essential amino acids lysine and tryptophan and lack important micronutrients such as provitamin A, iron, and zinc. The over-dependence of millions of the poor on maize results in poor health, stunted growth, reduced capacity for physical activity, and in extreme cases high incidence of nutritional deficiency diseases such as kwashiorkor, anemia, and corneal blindness.

Micronutrient malnutrition alone affects more than two billion people, mostly among resource-poor families in developing countries. For example, more than 300 million people in India suffer from micronutrient deficiencies, and 35% of the world’s malnourished children live in India. Maize cultivars that combine high grain yield with good amino acid composition, increased levels of pro-vitamin A and zinc concentrations could enhance production while improving nutrition, health, and the quality of life, in areas where poverty and low incomes limit access to diversified diets, dietary supplements, or fortified foods (Meenakshi et al., 2006; Ortiz-Monasterio et al. 2007; Pfeiffer and McClafferty 2007).

More than two-thirds of the global maize production was used as animal feed in the late 1990s, and this proportion is expected to grow, particularly as incomes rise and create greater demand for animal products (Pingali 2001). Typical maize grain consists of more than 70% starch (about 90% of the endosperm), about 10% protein, and 4% oil. Maize is primarily a source of energy in animal feeds (Glover and Mertz 1987). Grain yield is the primary trait to improve in maize for commercial feed and the primary target of most maize breeding programs, and especially for commercial maize programs. There is also scope for breeding maize with improved protein quality, increased content and quality of oil, and enhanced micronutrient content of grain.

In some livestock production applications, maize in animal feed suffers from the same problems of deficiencies in methionine, lysine and tryptophan that are encountered in maize-based human diets. Quality protein maize (QPM) developed by CIMMYT during the 1970s–80s has enhanced levels of lysine and tryptophan. At present, the most promising application for QPM in animal feeding is on-farm use in tropical smallholder swine production (Atlin et al. 2010). However the prospect of developing yellow maize with high essential amino acid content promises new avenues for livestock applications. Carotenoids and vitamins are essential micronutrients in poultry diets and pro-VA-enhanced yellow maize may have value as poultry feed. Oil has greater energy content than starch, and is thus desirable in that oil content can be increased without reducing grain yield.

Where smallholder farmers practice mixed livestock-cropping systems, or where specific commercial markets exist, there is often interest in using maize stover as feed; there may be scope to improve the energy content and digestibility of stover without compromising grain yield (Blummel and Friesen 2009). Parenthetically, characteristics associated with the increased nutritional value of stover are similar to those valued for biofuel (ethanol) production, making this an area of considerable global interest (Hansey et al. 2010). In conclusion, although breeding maize for use as feed is primarily a matter of breeding for increased grain yield, there are important opportunities to add value by characterizing and selecting maize to improve other traits associated with nutritional quality.

In this Strategic Initiative, conventional breeding and molecular tools will be used to develop nutritionally enriched maize cultivars adapted to production environments in Latin America, South Asia, and sub-Saharan Africa. National research systems and the private sector will be involved in development, testing, and adoption of nutritionally enriched maize OPVs and hybrids in their specific niches. The germplasm development work undertaken will be closely linked with TA4 (Agriculture, Nutrition and Health) to strengthen associations of product development with health and nutrition research as well as product delivery and thus maximize benefits to users and consumers. As part of varietal dissemination, special emphasis will be given to education on nutrition and cooking to optimize the impact of the biofortified maize.

Maize processing involves a combination of activities, which are performed at different stages to develop specific products. Processing contributes to food security by reducing waste and losses, increasing food availability and marketability, and improving nutritional quality, bioavailabilty, and safety. As new maize varieties with unique traits are developed, it is likely that kernel properties can change. This will present a challenge to processors, who can only achieve greater product quality when they process maize that has consistent and predictable properties. For example, one of the first steps in dry milling is tempering/soaking and one of the steps in wet milling is steeping. Ideally, kernel water absorption rates during these processes should be uniform. However, the rate can be affected by endosperm hardness, pericarp thickness, kernel size and shape. Ruan et al. (1992) suggested that the pericarp is a barrier to water absorption.

More recently, Ramos et al. (2004) reported that most of the hydration occurs through the pericarp and that pericarp thickness may affect moisture absorption rate. Another important quality characteristic of maize is its hardness, since this influences grinding power requirements, dust formation, nutritional properties, processing for food products, and the yield of products from dry and wet milling operations. Kernel hardness and differences in kernel composition have been suggested to affect water absorption rate. Therefore, information on physical and chemical properties as they relate to end-use processing characteristics and micronutrients retention is needed.

Several authors have reported that fermentation improved the nutritional quality of the product (FAO 1992). Fermentation has many benefits. It is feasible at a small scale, inexpensive, does not require additives, and confers organoleptic characteristics to the food product according to the habits and requirements of the consumers. Fermentation can occur spontaneously because of the lactic bacterial surface microflora (Panda et al. 2007). Phytates, found in grains and other fiber rich foods, bind iron and zinc and thus reduce absorption. Food processes such as soaking and fermentation have been found to decrease the phytate content of maize products and thus may increase absorption.

Maize can also play a very important role in the poultry and livestock industries in sub-Saharan Africa. The whole maize plant—including young maize stems, leaves, the husks, and cobs—can be consumed by livestock. Silage from the maize plant is an excellent and highly nutritious dry-season feed for ruminants. Maize residues after grain harvest can be used as livestock feed. Stalks can be used for fencing, roofing, and as fuel wood. One of the least exploited research areas in sub-Saharan Africa is the use of maize as a forage crop. Whole or ground maize grains are used as a feed ingredient in the poultry industry and also in concentrated supplements for sheep, goats, and cattle. Sorghum, millet, cowpea, groundnut and other crop residues are sold for animal feed in some countries. Market prices for crop residues vary from USD 40 per ton at harvest to USD 130 per ton during the next season, implying that storing crop residues can yield substantial economic benefits (de Leeuw 1997). Improving the quality of maize stover will thus bring benefits for animal feeds.

Progress to date and lessons learned

Several biofortified maize cultivars have been developed at CIMMYT, IITA, and other public and private institutions. The primary target traits for nutritional enrichment in maize have been protein quality, pro-VA, and mineral (Fe and Zn) concentration in the endosperm. Significant advancements have been made especially at CIMMYT in developing QPM germplasm that contains twofold higher lysine and tryptophan content than conventional maize, along with greater agronomic performance. The *opaque2* mutation, responsible for increased lysine and tryptophan levels, was first associated with deleterious pleiotropic effects resulting from softer endosperm, including increased susceptibility to insect damage, higher ear rot incidence, and a yield penalty of approximately 25% due to reduced grain density.

However, it was noted that in F_2 crosses between *o2* homozygotes and normal endosperm types, some *o2* segregants had relatively harder, more vitreous endosperm, and that lines could be fixed for this endosperm “modification,” making them less susceptible to the deleterious pleiotropic effects of earlier *o2* selections. Several breeding programs, notably CIMMYT, the University of KwaZulu-Natal in South Africa, and Crow’s Hybrid Seed Co. in the US initiated long-term breeding programs to develop and release QPM inbreds, hybrids, and OPVs (Prasanna et al. 2001; Atlin et al. 2010). CIMMYT, in collaboration with IITA and national research systems in 17 countries of SSA, has developed a broad range of QPM cultivars responding to the needs of different countries and agroecological zones.

Commercial QPM seed is currently available in all collaborating countries and, based on average 2003–2005 seed production, approximately 200,000 hectares are being planted to QPM cultivars and in some instances nutritional impacts quantified (Gunaratna et al., 2010). A number of national programs across Latin America, Africa, and Asia have released QPM hybrids and OPVs, utilizing the QPM germplasm developed by CIMMYT and IITA (Prasanna et al. 2001; Krivanek et al. 2007; Atlin et al. 2010).

Since 2004 both CIMMYT and IITA have conducted maize research under HarvestPlus at . The primary focus of HarvestPlus-Maize research is identification and development of tropical germplasm as source of pro-VA and development of high-pro-VA hybrids and OPVs. As a secondary objective, the program has identified maize varieties with high zinc concentrations. Maximum pro-VA concentrations between 6 and 8 ppm have been validated in germplasm in development. Breeding for enhanced pro-VA has reached an advanced stage, and experimental hybrids have been produced at both IITA and CIMMYT and evaluated by the Zambian Agricultural Research Institute, SeedCo, and ZamSeed, key partners of HarvestPlus.

Research on carotenoid retention during handling and processing is also conducted at CIMMYT and IITA. Research on recurrent selection as a strategy to develop OPVs with increased pro-VA concentration has demonstrated an increase of at least 1 ppm for each cycle of selection. OPVs for enhanced pro-VA are being developed by conversion of commonly used OPVs or by formation of new varieties. All breeding efforts in this SI will include not only the evaluation for stress (mainly drought and low nitrogen) and higher potential environments but also the conversion of the best drought and low nitrogen tolerant elite lines to enhanced VA.

Recently, CIMMYT scientists in collaboration with the University of Illinois, Cornell University, the National Maize Improvement Center of China, China Agricultural University, and Michigan State University identified two genes (*LycE* and *Crt-RB1*) in the carotenoid biosynthetic pathway with major effect on VA concentrations (Harjes et al. 2008; Yan et al. 2010). Molecular markers for assaying functional polymorphisms within these two genes have been developed and validated across diverse genetic backgrounds; these are being used in the CIMMYT pro-VA breeding program and hold great potential for national breeding programs. In addition to protein quality and micronutrient traits, several other nutritionally significant traits such as low phytate content (Raboy et al. 2000) and high vitamin E, ascorbate, and folate contents (Naqvi et al. 2009) have been discovered, but these require more detailed studies before proceeding to breed germplasm with nutritional efficacy.

The long experience of CIMMYT and IITA on QPM holds many important lessons that can be applied to other biofortification efforts. Successful development and adoption can only occur when there is assurance of competitive agronomic performance of the nutritionally enhanced germplasm, easily accessible screening tools for breeding and quality control, effective seed production systems, economic benefits and market incentives for producers, and strong partnerships with national research programs and health and agricultural ministries (Atlin et al. 2010). Biofortification strategies must include both breeding and improved agronomy practices, as micronutrients like zinc are highly dependent on both soil quality and farming practices.

Biofortification interventions have a long-term impact on the nutritional status of the populations most in need of them, and most of the nutritional compounds are invisible to the farmers. However, based on the QPM experience, one of the most effective ways to promote the adoption of such cultivars in countries where maize is the staple crop is to focus on the development and dissemination of low-cost biofortified OPVs that are agronomically superior to local landraces. This could likely be achieved in maize-dependent countries if most OPV breeding effort shifted to biofortified maize, especially for hidden characters like zinc, essential amino acids and vitamin E, to name a few.

Why international agricultural research?
CIMMYT and IITA have established protocols and the requisite facilities and expertise that allow assessment of the nutrient composition in maize germplasm and breeding materials. The Centers are committed and mandated to forge partnerships with advanced research institutes and national research programs in joint projects for the nutritional enrichment of maize, and are also key research partners of HarvestPlus. CIMMYT and IITA scientists have a long history of developing and disseminating QPM varieties. CIMMYT scientists in collaboration with University of Illinois and Cornell University recently discovered key genes governing critical steps in the carotenoid biosynthetic pathway, thus enabling marker-assisted selection for speedier and cost-effective development of pro-VA-rich maize cultivars. CIMMYT scientists have also generated germplasm with significantly higher levels of zinc.

CIMMYT and IITA are able to generate and coordinate the complex partnerships needed to develop high-yielding, stress-tolerant biofortified maize varieties, demonstrate their efficacy in improving nutritional status of affected populations, support national partners in implementing the seed production and monitoring systems needed to ensure that the quality trait reaches farmer, and advise on strategies that will make biofortified maize attractive to producers and accessible to poor consumers.

Transgenic biofortification approaches are a special case where complex public–public and public–private international partnerships will be required. Transgenic approaches will be used in cases where genetic diversity in the maize gene pool is limited or where the environmental effect is very large. In those cases, a clear strategy for intellectual property management, regulatory approval and commercialization can be designed and funded. Country-specific strategies must be developed for transgenic variety deregulation and release, due to the differences in regulations and acceptance between them. Universities, advanced research institutes and private companies will be essential partners whenever transgenic approaches will be taken. Through its participation in projects to develop germplasm tolerant to low-N fertility and drought, CIMMYT has substantial experience in public–private partnerships designed to deliver transgenic varieties to smallholders in Africa—experience directly applicable in projects on transgenic, biofortified varieties.

Researchable issues

- Discovery, characterization and use of genetic variation in the maize gene pool (including breeding germplasm) for nutritionally valuable traits, including essential amino acids, carotenoids, and Zn.
- Gene discovery and allele or haplotype mining for enhanced levels of nutritional traits such as protein, starch, oil, anthocyanins, forage quality traits, phytic acid, folate, ascorbic acid, lignin, cellulose.
- Gene expression profiling and allele selection for genes governing critical steps in the nutritionally important biosynthetic pathways.
- Grain, plant and crop physiological responses or pleiotropic effects of breeding selection for traits conferring enhanced nutritional value.
- The effects of common grain handling, storage, and food processing methods (e.g., lime-cooking, fermentation, milling and roasting) on the retention and bioavailability of nutrients in maize.
- Processing maize grain for improved nutritionally quality and enhanced nutrient bioavailability
- Breeding and selection of maize varieties whose residues are low in lignin with potential for higher digestibility without reduction in grain yield.
- Develop maize populations with desirable stover characteristics for use in ruminant production.

Outputs

1. High-throughput and low-cost phenotypic screening methods developed and validated for use in breeding and selection for a range of nutritionally important traits.
2. High-value source germplasm for specific nutrients/compounds.
3. Inbred lines, hybrids, and OPVs with >8 μg/g pro-VA, 50–100% higher lysine and tryptophan (vs. normal maize), and kernel zinc >30 ppm.
4. Functional markers and high-throughput assays using the best available technologies for genes and functional polymorphisms governing critical steps in the nutritionally important biosynthetic pathways.
5. Web-based database of genotypic and phenotypic attributes for food, feed, industrial, and end-use quality of elite and diverse maize genetic materials.
6. Knowledge about effective conventional and molecular breeding strategies for enhancing nutritional value of maize.
7. Information on micronutrient retention and bioavailability in common maize processes.
8. Traditional and novel maize-based food products with enhanced nutritional quality and bioavailable nutrients
9. Maize varieties, lines, hybrids, and source materials with desirable characteristics for stover production identified/developed.

Research and development partners

HarvestPlus and institutions in LAC (INTA, Nicaragua; CENTA, El Salvador; DICTA and UNAM, Honduras; ICTA, Guatemala; ORE, Haiti), South & SE Asia (ICAR Institutes of India; PARC of Pakistan; Indonesia; Nepal; Bangladesh); and Africa (Zambia, ZARI; FARA, ASARECA, CORAF, IAR and NAERLS (Nigeria), INERA (Burkina Faso), FAES (Senegal), KEPHIS (Kenya), IKIRU and IIAM (Mozambique), CRI (Ghana), INRAB (Benin), IER (Mali); Private seed companies including ZamSeed, SeedCo, Premier Seeds Nigeria Ltd and Alheri Seeds Ltd (SSA), Monsanto/Pioneer/Syngenta/Bioseed of India and Ceres, Aspros, Monsanto, Pioneer in Latin America, with whom CIMMYT and IITA have established collaboration and expressed interest to evaluate nutritionally enriched, agronomically superior varieties and hybrids.

HarvestPlus and TA4, plus numerous universities and advanced research institutes like University of Wisconsin , Flinders University, Cornell University, Tecnológico de Monterrey, CGIAR centers (CIP, CIAT, ILRI) along with NARSs (CINVESTAV, INIFAP, and the Colegio de Posgraduados, in Mexico; IARI, New Delhi; and CAAS, China) will partner or synergize with CIMMYT and IITA research, because of their relative strengths in human nutrition, food technology, nutrient analysis, feed/forage analysis, micronutrient research, and other complementary topics.

For pro-VA-enriched maize, HarvestPlus, CIMMYT and IITA have built partnerships with stakeholders in Zambia, including Ministry of Agriculture (including research and extension divisions), Ministry of Health, NGOs (Care International, Program Against Malnutrition, World Vision) and national research institutes (NISI R). Work on QPM has been strongly supported by NGOs in Africa (Sasakawa Global 2000, World Vision International, Catholic Relief Services, NARS and extension services), Ministries of agriculture in El Salvador and Nicaragua. We will build on these partnerships and link with CRP4 to ensure adaptation and dissemination of the nutritionally enhanced germplasm.

Outcomes

- Maize researchers in at least five developing countries in sub-Saharan Africa, Asia and LAC will use the biofortified source germplasm in their breeding and research programs.
- Maize researchers in public and private sector institutions will validate the agronomic performance of elite biofortified germplasm from this project, and will consider variety release and dissemination.
- Breeding programs in at least five target countries use phenotyping methods and/or marker-assisted selection for improving nutritional quality of maize, thereby enhancing genetic gains and breeding efficiency.
- Scientists and other partners will apply skills learned and knowledge gained from this project to achieve greater effectiveness in their research programs.
- Improved nutrition and health status of children and women of child-bearing age from consuming nutritionally enhanced maize varieties.
- Improved protocols for routine screening of maize varieties for forage quality.

Key milestones

2011: At least five donor lines identified for each of the important nutrients in tropical and subtropical germplasm. More than 200 inbred lines and 400 accessions characterized for grain and 100 accessions characterized for stover quality.

2012: High-throughput and low-cost screening methods standardized for at least two nutritionally important target traits (e.g. vitamin E, zinc, ascorbate, and folate).

2013: More than 30 experimental hybrids/OPVs selected for high pro-VA, QPM and zinc tested in multi-location trials. Molecular markers for at least two nutritional quality traits identified/developed. Nutrient retention during storage and processing in nutritionally enhanced maize cultivars determined. Phenotyping protocols disseminated in at least two target countries annually. At least two nutritionally enhanced varieties tested for consumer acceptability and promoted for consumption at the household level in target countries. A minimum of five traditional methods of processing improved and promoted. At least five traditional maize food products nutritionally improved and promoted for consumption.

2014: Phenotypic data on nutritional quality traits of maize genetic resources integrated into public database. Promising QPM and pro-VA-enriched varieties and hybrids, selected by partners from regional trials, are evaluated in advanced and farmer-participatory trials to confirm nutrient levels and generate required data for cultivar registration and release. In partnership with the national research and extension systems, and the private sector in target countries, evaluate, validate, produce and develop a dissemination strategy for pro-VA-enriched maize cultivars (Link with CRP4).

2015: New genes and favorable alleles identified for enhanced carotenoids, essential amino acids, oil and fatty acids or other important nutritional compounds/elements. A catalog of important genes and favorable alleles in elite breeding source germplasm prepared and made available.

2016: At least five new biofortified cultivars (with at least 50% increase in lysine, tryptophan, provitamin A, and zinc concentrations in maize grain) developed and released in target countries by 2016. At least one seed company or community-based seed producer group producing seed of biofortified cultivars for marketing in each of two or more target countries. More than 100 scientists/technicians from national research systems trained in micronutrient analysis (Link with SI on capacity building) during the 6 years of this initiative.

Linkages with other SIs
SI 7 will make use of high-potential, stress-tolerant germplasm developed in SI 4 and SI 5 as parental materials for introgression of genes affecting pro-VA content, and will use new tools developed in SI 9, particularly doubled haploids, to speed line extraction. Rapid-cycle genomic selection may be potentially used to speed population improvement for complex quantitative traits, such as kernel micronutrient concentrations (especially zinc). SI 1 will provide guidance on technology targeting, value chains, marketing strategies, institutional innovations and policy options for effective technological dissemination and impacts.

What's new in this initiative?

- The role of biofortification as a strategy to combat malnutrition and associated health problems has recently gained global recognition (Copenhagen Consensus 2008) as one of the five highest priority investments, based on the costs and benefits of the solutions, to combat the greatest global challenges.
- This Strategic Initiative shall provide technological knowledge and germplasm base to TA4 (*Agriculture, Health and Nutrition*) which aims to provide multidisciplinary, multi-institutional and policy support to achieve greater impacts than ever before through biofortification.
- The Initiative shall create strong links between molecular genetics (e.g. allele mining and marker-assisted selection), biochemistry (e.g. high-throughput phenotyping), nutrition (e.g. factors influencing bioavailability) and plant breeding, for enhanced effectiveness of maize biofortification strategy.

Targets and impact estimates
Targeting of this Initiative is based mainly on overlap between percentage of malnourished people in the target country and the contribution of maize to total daily calorie intake. For **pro-VA** maize the primary target country is Zambia, with secondary emphases on Ethiopia, Angola, Ghana and Nigeria, and spill-over to several countries including India, China, South Africa, Zimbabwe, Haiti and Mexico. For **QPM** the primary target countries are Guatemala, El Salvador, Honduras, Nicaragua, Ethiopia, Malawi, Zimbabwe, Zambia, Uganda, Kenya, Ghana, and Nigeria, with spill-over benefits to many countries in sub-Saharan Africa, Asia and Latin America, including Mali, Benin Republic, India and China.

Development of new nutritionally enhanced cultivars (with 50–100% increase in essential amino acids, pro-vitamin A and micronutrient content) and their adoption in target countries in sub-Saharan Africa, Asia and LA, will have significant nutritional benefits to at least 100,000 resource-poor and malnourished families by 2016, and 200,000 families by 2020 with regard to VA, and millions of consumers with regard to QPM. This initiative would have potential impact in terms of disability adjusted life years and enhancing the productivity of malnourished and resource-poor maize-based farming communities.

Other issues
Gender
In developing countries, women play major roles in maize production, storage, and processing and food preparation. An opportunity often missed in strategies for improving under-nutrition is the incorporation of a gender perspective. Women are key actors responsible for both household nutrition and household agriculture in terms of food crops in developing countries. Women's abilities in this regard are limited by the larger social construct of roles and responsibilities of women relative to men—with a power balance that is usually tilted toward men. Gender inequality limits women's ability to earn or control income, acquire resources, and make decisions, which in turn limits their ability to ensure household nutrition and production of nutritious food crops. Although extensive research and training

has occurred in the agriculture field, and to some extent in the nutrition field, integrating gender issues into agriculture and nutrition work remains limited.

Direct involvement of women through active participation in planning, design, implementation, and evaluation empowers them and imparts a stronger sense of ownership and a more pronounced stake in project success. The needs of women, children, and other vulnerable groups such as pregnant women and people (especially young adults) living with HIV/AIDS will be addressed by ensuring the involvement of women and young adults in all phases of implementation of the initiative. The needs of women, children, and other vulnerable groups such as pregnant women and people living with HIV/AIDS will be addressed by ensuring that the design includes mechanisms and strategies to promote and facilitate women's involvement in all phases of implementation. This initiative will link with CRP4 (*Agriculture, Nutrition and Health*) and target women for nutrition, health, and food security interventions. Women are usually responsible for preparing maize foods for home consumption.

Capacity building

SI 7 will build capacity in biofortified maize variety development through organization of short-term courses for breeders and analytical service providers, especially on screening tools for phenotyping nutritional and industrial quality traits. Capacity building will also be provided by the engagement of NARS and private sector scientists in research and training visits, also their in-depth incorporation of in SI 7 research as graduate students and post-doctoral fellows. SI 7 will also link with CRP4 for development of information packages on biofortified maize, including maize value chains, impact assessment and policy analysis, food processing information and nutritional education.

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Strategic Initiative 8. Seeds of discovery: Opening the "black box" of maize genetic diversity

Value proposition
Foster the targeted mobilization of novel native genetic diversity in breeding programs worldwide by using advanced technologies to fully catalog the genetic heritage of international maize seed collections, and to make the resulting information and knowledge freely available—through a user-friendly, web-based platform and a marker-assisted introgression pipeline.

This Initiative has an immense leverage and impact potential. It will enable the entire maize breeding and research community worldwide to fully utilize the native genetic diversity in the world's maize genetic resources, also to accelerate breeding gains and counteract the combined and growing negative effects of climate change and scarcity of water, land and nutrients. Genetic diversity is an essential component of breeding progress, and so far the plant breeders have utilized only a minuscule fraction of this bio-resource.

Justification
General background
Maize genetic diversity has been assembled and conserved over many decades in seed collections such as those held by CIMMYT and IITA. This diversity has furnished the building blocks for breeding modern cultivars. However, only a tiny fraction of the vast genetic diversity of maize collections has been put to practical use in breeding programs worldwide. The sheer size of the seed collections, as well as technological limitations, has made comprehensive phenotypic and molecular description of the collections impossible. This situation is now rapidly changing with the new marker systems, next-generation sequencing and precision phenotyping technologies. Breeders are not only eager for adequate phenotypic and molecular information about seed collections, but they also need tools for mining such information and ways for accessing diversity in a more targeted manner. This Strategic Initiative will comprehensively address these constraints and thus assist breeders in the identification of useful native diversity and targeting its mobilization into maize breeding programs worldwide.

Why international agricultural research?
CIMMYT and IITA collectively hold[12] the world's most diverse collection of maize diversity, including nearly 25,000 landraces, teosinte/*Tripsacum* wild relatives, and 3,000 elite inbreds, pools, and populations. These collections also serve as intermediaries between "upstream" basic and strategic research and "downstream" applied maize breeding. The *ex situ* collections are directly linked to world-class plant breeders, agronomists, molecular biologists, and socioeconomists, as well as global partnerships to apply science for development. The value-added initiative proposed will be global in nature and the outputs freely shared to foster their widespread, beneficial use.

Current status of research
Molecular diversity in both natural and elite maize germplasm from several countries has been extensively analyzed with microsatellite/SSR markers (Prasanna et al. 2010). CIMMYT provided leadership in analysis of a large collection of tropical/subtropical maize accessions and genetically heterogeneous landraces, the latter by using a population bulk fingerprinting strategy (Warburton et al. 2008, 2010).

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[12] As guided by the International Treaty on Plant Genetic Resources for Food and Agriculture (http://www.planttreaty.org).

Compared with the genomes of other crops, single-nucleotide polymorphism (SNP) frequency in maize is high, with one SNP every 28–124 bp (Vroh Bi et al. 2006). Molecular characterization of >600 maize inbred lines at CIMMYT has recently led to the discovery of SNP markers with no germplasm-specific biases and the identification of informative haplotypes (Lu et al. 2009; Yan et al. 2009). Based on haplotype information, a versatile core set of inbreds that captures 90% of the haplotype diversity of the entire panel has also been established. A maize database and resource for SNP discovery and trait dissection, in which genotype and phenotype data can be accessed for diverse maize inbreds and populations, has become available (Zhao et al. 2006). Strategies for formulating core collections using passport, phenotypic, and molecular/biochemical data have been formulated at CIMMYT (Franco et al. 2006).

Researchable issues

- Comprehensively characterizing the genetic richness and the phenotypic diversity of maize, and identifying, by association mapping, novel, potentially useful alleles, haplotypes, allele combinations, and donors for yield potential, tolerance to key abiotic/biotic-stresses and nutritional-quality traits.
- Identifying selection imprints and allele-frequency clines across environmental gradients.
- Establishing a pre-competitive "commons" domain for delivery of diversity data and knowledge as global public goods—which discourages intellectual property (IP) protection on raw materials and basic knowledge required for maize breeding while encouraging the use of SI products for the development of cultivars, irrespective of their IP status.
- Leveraging top-end information technology (IT) tools and expertise to design a researcher/breeder-oriented web interface—for visualizing, querying, and mining trait, molecular, and geo-referenced passport data across the entire set of accessions in an integrated manner.
- Mobilizing novel diversity into breeding programs: (1) via a pre-breeding introgression pipeline that assists maize breeders in the mobilization of novel alleles into their breeding programs; (2) by strengthening/refining existing seed-conservation and delivery operations.

Outputs

1. Phenotypic and molecular descriptions of conserved maize diversity generated and integrated with geo-referenced passport data, and packaged and delivered to the global maize community via a researcher/breeder-oriented MAIZE Diversity Portal.
    - An information-rich data repository is made available on the web as a global public good, which allows integrated queries of molecular, trait, and geo-referenced passport data.
    - Identification of donors for internationally relevant priority traits:
        - *Biotic stresses*: Diseases (e.g., maize streak virus, gray leaf spot, leaf blights, rusts, downy mildews, banded leaf and sheat blight, stalk and ear rots, mycotoxins); Pests (e.g., stem borers, maize weevil, large grain borer, nematodes); *Striga*
        - *Nutritional quality*: Pro-vitamin A, endosperm protein quality; kernel micronutrients (especially zinc)
        - *Abiotic stresses*: Drought, low N, high temperature, acidity/Al toxicity, waterlogging,
        - *Yield-related traits*
        - *High-value specialty traits (e.g., oil)*

While evaluating for the above phenotypic traits, due emphasis will be placed on sampling strategies as well as statistical designs for analysis of genetically heterogeneous populations (e.g., landraces, wild relatives) vs. genetically homogeneous materials (e.g., inbred lines).

- Data-mining results identifying accessions that carry desirable traits, alleles, haplotypes, and allele combinations are uploaded to the MAIZE Diversity Portal to assist researchers and breeders in the refined targeted use of genetic variation.
- The MAIZE Diversity Portal is cross-linked with other maize and IP-related internet resources to facilitate more comprehensive and sophisticated user queries.

2. Seed from global maize diversity collections is made more easily accessible to maize researchers, breeders and farmers worldwide.
    - Collections held by CIMMYT and IITA are systematically and securely conserved, backed up, rationalized, kept transgene/pathogen-free, and coordinated with other collections.
    - New germplasm is added to fill critical ecological, national, and user-defined gaps in collections, and to counterbalance *in-situ* and on-farm genetic erosion.
    - CIMMYT- and IITA-held maize collections are integrated into IT-facilitated global networks that enable users to contribute data and query germplasm across institutions.
3. Elite germplasm with novel and useful introgressed genes/genomic regions from exotic accessions becomes available, allowing researchers/breeders worldwide to improve key target traits and enhance genetic gains.
    - New alleles for candidate genes with large effects on biotic and abiotic stress tolerance, quality, and other high-value traits are introgressed into elite backgrounds.
    - Elite pre-breeding populations become available which broadly sample genetic variation for highly polygenic traits from under-utilized race groups via rapid-cycle genomic selection.

Research and development partners

Maize phenotyping network participants at national research programs, advanced research institutes, universities, and the private sector; GCP Challenge Initiatives; sequencing/genotyping experts at Cornell University (GBS and Panzea database), BGI-Shenzhen and CINVESTAV; IP experts at PIPRA and elsewhere; IT experts at universities, foundations, and in the industry; genomics, genetics and breeding software developers at universities; data analyzers at universities, advanced research institutes, and companies; the Maize and Sorghum USDA AFRI CAP project; maize and IP on-line resources at Iowa State University (MaizeGDB), NCBI (GenBank), and CAMBIA (Patent Lens); national research programs and other seed banks protecting *ex situ* and *in situ* crop diversity; and the Global Crop Diversity Trust. Breeders at CIMMYT, IITA, national research programs, advanced research institutes, universities, and seed companies mobilizing novel alleles into breeding programs via seeds or introgression lines; patent offices using the MAIZE Diversity Portal for evaluating prior art during the patenting process; plant scientists worldwide using the MAIZE Diversity Portal, seeds or introgression lines for research.

Outcomes

- The global maize community will gain free access to a quantum leap in our understanding of the genetic differences and similarities among maize varieties at the genome, chromosome, and genetic-locus/sequence levels, and in our understanding of the potential of key traits.
- Research and breeding programs worldwide will mobilize significantly more genetic variation from conserved maize accessions and utilize the knowledge available through the MAIZE Diversity Portal.
- Key-trait donors, and distilled information on phenotypic and molecular diversity, will enable faster and more significant genetic gains in maize-breeding programs worldwide.
- Breeders worldwide will use increasingly sophisticated breeding approaches for oligogenic or polygenic traits, supported by an understanding of the effects of genetic variation at distinct loci.

- Breeding programs will achieve more effective design of "cisgenics", informed by new insights into gene functions, derived from comprehensive marker-trait association studies.

Key milestones

2011: Business plan and terms of engagement developed for research partners.

2011: Global Maize Phenotyping Network formed; priority traits, methods, research partners, and accessions to be characterized agreed upon. Decisions taken about which databases, seed bank management systems and web portals to build upon, and on the kind of IT expertise required to implement the SI. Legal and publicity arrangements for creating a pre-competitive "Commons" domain for data delivery validated by legal and public-relations experts. Genomic selection (GS) initiated in at least five pre-breeding populations to sample under-utilized maize races.

2012: Raw, simple version of the database behind the future web portal available and ready to accept molecular and trait data streams (milestone shared with WHEAT SI 8 on *Opening the "blackbox" of wheat genetic diversity*). CIMMYT- and IITA-held maize collections meet best-practice standards, as recognized by QMS or other certifications.[13]

2013: Ultra-high-density SNP genome-profiles (10^5–10^6 loci) for most accessions (five individuals per population) generated via GBS and uploaded to database. At least 40 (candidate) genes of known functions sequenced across trait-dependent core sets, with sequenced genes matching targeted traits. Marker-assisted introgression pipeline established and working for a number of priority cases. First, simple version of the MAIZE Diversity Portal available to provide CRP members with on-line access to data streams (output shared with WHEAT SI 8). Compatible seed bank management systems deployed (milestone shared with WHEAT SI 8).

2014: Evaluation completed of approximately 40 key agronomic, nutritional/grain quality and abiotic/biotic stress-related traits across trait-dependent core sets. A second set of varieties, selected on the basis of molecular data, added to the sets. Twenty years of trait data from field trials of participating seed banks and breeding programs uploaded. Set of priority traits re-evaluated and adjusted.

2015: Genomes of a set of thoroughly phenotyped accessions fully or partially re-sequenced (e.g., via exon-capture or skim-sequencing). Fully refined version of the MAIZE Diversity Portal completed and on-line. Critical diversity gaps filled in CIMMYT- and IITA-held *ex situ* maize collections.

2016: Field trials for second-series core sets/traits completed. Novel favorable alleles and haplotypes identified by SI members and uploaded to the MAIZE Diversity Portal. Network of data miners adding value to the MAIZE Diversity Portal established. MAIZE Diversity Portal cross-links with other on-line resources such as GeneSys, MaizeGDB, GenBank and the Patent Lens. Elite pre-breeding populations sampling underutilized maize races derived from at least four cycles of GS made available to breeders.

What's new in this initiative?

This SI is the first attempt to comprehensively characterize the inherent heritage of one of mankind's three major cereal crops. The goal is to produce a world-first, breeder/researcher-friendly "catalog" for the CIMMYT- and IITA-held maize seed "libraries". The SI, however, will go well beyond a simple stock-taking of diversity, to promote flow of useful diversity into research and breeding programs, not only via well-characterized accession seeds but also by capturing into elite backgrounds both large-effect QTL alleles via marker-assisted introgression and small-effect alleles via rapid-cycle genomic selection.

[13] Excellence Through Stewardship certification (http://www.excellencethroughstewardship.org).

Targets and impact estimates

Global public and private maize-breeding programs of any size and at any location, provided researchers adhere to the "commons" philosophy; maize researchers at CIMMYT and IITA, universities, national research programs, and advanced research institutes worldwide; maize seed banks at national research programs and advanced research institutes; policy-makers and regulatory authorities promoting/regulating the conservation and use of maize biodiversity.

This SI targets a highly leveraged intervention point upstream in the maize-value chain; the impacts could be significant after an initial lead time, during which novel allele combinations are re-packaged in improved cultivars. Assuming that within 15–25 years the genetic component of the annual yield-growth rate (0.86% $year^{-1}$) can be increased by 5–20% to 0.90%–1.03% per year by mobilizing novel diversity into breeding programs, an additional 0.37–2.7 million metric tons of grain, valued at 55–410 million in today's US dollars, would be produced. Furthermore, if within 15–25 years, worldwide NPK fertilizer applications for maize[14] could be reduced by 0.5–5% as a result of introgressing into elite germplasm alleles that enhance nutrient efficiencies, 130,000–1,300,000 tons of nutrients, currently valued at USD 113–1,130 million, could be saved annually.

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[14] 17.4/6.4/1.7 million metric tons of $N/P_2O_5/K_2O$ are projected to have been applied to maize field worldwide in 2009/10, respectively (IFA: http://www.fertilizer.org/ifa/Home-Page/STATISTICS; FAO: ftp://ftp.fao.org/agl/agll/docs/cwfto11.pdf).

Strategic Initiative 9. New tools and methods for NARS and SMEs to increase genetic gains in maize breeding

Value proposition

Provide maize breeders in the developing world with genomics and bioinformatics tools, breeding and phenotyping approaches that enable them to double their breeding gains given limited resources.

Estimated impact	2020	2030
Benefit to the poor	The target area includes an estimated 616 million maize-dependent poor, of whom 422 million live in rural areas, and an estimated 59 million maize-dependent malnourished children	
Annual production increase	0.4 million tons of maize grain	5.5 million tons of maize grain
Food calorie equivalent (at 2000 kcal)	1% of the caloric intake of 609 million maize consumers	15% of the caloric intake of 609 million maize consumers
Annual value addition	USD 60 million	USD 825 million
Benefit to the environment	Increased land and water use efficiency; increased deployment of maize genetic diversity	
Others	Strengthening of local entrepreneurs and innovation	

Justification

General background

Multinational seed companies in temperate regions are achieving dramatic gains in maize breeding through integrated use of precision phenotyping, marker-based selection with low-cost, high-density genotyping, doubled haploid (DH) technology, improved data management and analysis, and decision support tools. These tools, now nearly universally applied by the largest commercial maize breeding programs, have allowed private-sector breeders to greatly increase selection intensities and reduce breeding cycle times, and appear to be resulting in substantially increased rates of genetic gain (Eathington et al. 2007). Applying the same tools for breeding research in tropical maize would help provide the 2.4% rate of yield gain needed between improved agronomics and genetics to meet the increasing demand for maize in developing countries in coming decades, without significantly expanding maize area at the cost of ecosystem health.

Changes in the operating environment for plant breeding programs are making the routine application of advanced breeding tools in small programs in developing countries feasible for the first time. These changes include the emergence of low-cost commercial genotyping services with far lower costs than in-house labs, and the development of publicly available breeding informatics systems, coordinated by the Integrated Breeding Platform of the Generation Challenge Program (GCP). Taken together, these innovations will permit a drastic reduction in breeding cycle times, with commensurate increases in genetic gains per year, through the implementation of rapid-cycle genomic selection or selection based on continually updated estimates of haplotype effects for biotic and abiotic stress tolerance, yield potential, and seed production ability.

Genomic selection (GS), the most radically transformative of the new breeding tools, is selection on the basis of marker or haplotype effects summed across the genome in a genomic estimated breeding value (GEBV), enabling prediction of breeding value or performance of individuals under selection. GS differs from current approaches to marker-assisted selection (MAS) in that it integrates information from all markers in GEBV estimation, rather than from a significant subset. The main conceptual difference between GS and other breeding systems is that the 'haplotype' rather than the line is the selection unit; lines are treated as experimental units in initial phenotyping.

CIMMYT, IITA, and ARI collaborators are exploiting the concept of GS in the design of more efficient maize breeding plans. Currently, the early phases of maize breeding programs are designed to estimate the general combining ability (GCA) of lines within the target population of environments (TPE) of a breeding program. GS-based programs could estimate both general (GCA) and specific (SCA) combining abilities for each haplotype in early testing by crossing subsets of lines to different testers; because each haplotype recurs across several lines its effects, with and across testers, could be estimated by considering line effects to be random. Similarly, haplotype effects across the TPE could be estimated in early testing. Large populations could be generated and evaluated without replication across testing sites, with each line evaluated in a single plot at only one location; haplotype effects across locations would be estimated considering line effects random.

These approaches could increase selection intensity and allow estimation of tester- and region-specific GEBVs in the initial testing phase. Treating the haplotype as the selection unit will permit small breeding programs to collaborate in “open-source” breeding networks—in which the local breeding program receives unique genotypes that have not yet been phenotyped, accompanied by GEBVs specific to their environment and testers. Combined with the increased gains achievable via reduced cycle time for genomic selection (the breeding cycle could be reduced to a single season, rather than the 5–7 years that is currently the norm), these approaches could increase the effectiveness of small breeding programs in the developing world. It is now increasingly realized that high-throughput genotyping will be of little value without high-throughput precision phenotyping, on which there has been considerable emphasis in recent years (Montes et al. 2007).

The use of doubled haploid (DH) techniques to rapidly develop inbred lines is again widespread among commercial maize breeding programs, particularly in Europe and USA, and to a limited extent in Asia (Röber et al., 2005). Factors making DHs increasingly attractive for the largest private-sector institutions include the development of better inducer lines, more efficient chromosome doubling methods, and protocols to efficiently introgress transgenes, especially stacked transgenes. Unfortunately, the available inducer lines are of temperate adaptation, so the development of haploidy inducer lines in tropical genetic background, currently ongoing under a CIMMYT collaborative project with the University of Hohenheim (Germany), promises to be extremely valuable to breeding programs in tropical and subtropical regions of Asia and elsewhere (Prasanna et al. 2010). Bouchez and Gallais (2000) demonstrated with simulations that use of DH lines will theoretically enhance the efficiency of recurrent selection schemes for traits with low heritability, particularly for breeding programs without access to offseason nurseries.

The recent focus on structural and functional genomics of diverse plants has highlighted another important challenge—how to integrate the different views of the genome that are provided by various types of experimental data and provide a proper biological perspective that can lead to crop improvement. Mapping and studying the genetic architecture of complex traits, and understanding the dynamic network of gene interactions that determine the physiology of an individual organism over time, are other major challenges that requires novel, quantitative and testable statistical solutions. Through this SI, we will strive to strengthen statistical genomics and bioinformatics research on maize, in partnership with advanced research institutions and private-sector partners, for effective utilization of modern genomic approaches for maize improvement.

Through collaboration among CIMMYT, IITA, advanced research institutes, the Generation Challenge Program (GCP), national research systems, and small- and medium-size seed enterprises, this Strategic Initiative will also refine the new breeding tools and develop strategies to permit their use by small breeding programs to address the problem of increasing productivity in tropical and subtropical maize production environments. Integration of advanced tools within breeding programs in Africa, Asia, and Latin America will result in increased genetic gains, more rapid development of resilient, high-yielding hybrids and open-pollinated varieties, and increased food security and incomes for millions of the maize-dependent poor. The aim is to double rates of genetic gains within the six-year life of this project.

Use of these new tools will result in more competitive national and regional seed companies and increase the availability of elite germplasm from public international agricultural research centers. Maintaining diverse sources of elite maize germplasm in the public domain is critical to the survival of local and regional seed companies and to the existence of competitive seed markets that serve the needs of a wide range of farmers and, in particular, poor smallholders.

Progress to date and lessons learned

Both breeding behavior (Carena et al. 2009) and QTL analysis (Ribaut et al. 2008) indicate that genetic control of drought tolerance in maize is complex and polygenic. Methods that reduce breeding-cycle time are needed to increase genetic gains for such “difficult” traits. CIMMYT is developing tropical doubled haploid (DH) inducers and rapid-cycle marker-based recurrent selection protocols for this purpose. DH inducers obtained from the University of Hohenheim (Germany) have been used to develop tropically-adapted inducers that will be available for distribution within 1.5 years.

The cost of genotyping with single-nucleotide polymorphism (SNP) markers is no more than 10% of the cost of simple sequence repeat (SSR) markers per data point, and the availability of efficient, rapid-turnaround commercial SNP genotyping services means that breeding programs no longer need (nor would find cost effective) in-house genotyping capacity. Even small NARS and commercial breeding programs can afford to genotype and apply marker-assisted selection in variety development. Both CIMMYT and IITA are now outsourcing most genotyping. Application of marker-driven, rapid-cycle recurrent selection methods has been demonstrated to increase breeding progress in commercial programs in the US (Eathington et al. 2007), but have not yet been applied to maize breeding in developing countries (Prasanna et al. 2010). CIMMYT has initiated over 30 marker-assisted recurrent selection populations to test these methods in breeding programs for Africa and Asia.

Genotyping costs are expected to drop by several orders of magnitude more in the coming year, as sequencing technologies are applied to genotyping. CIMMYT’s elite East African germplasm will be genotyped at a density of approximately 1,000,000 polymorphic features in 2010 by the pioneering “genotyping by sequencing” technology developed by the Buckler Lab at Cornell University. Routine high-density genotyping of all breeding lines in the CIMMYT and IITA programs, and extension of this technology to research partners, will transform maize breeding for poor smallholders, allowing the development of breeding systems based on genomic selection. High-density marker genotypes can be used to predict genotypic value (Heffner et al. 2009) and have been shown to be highly effective in predicting maize yield under stress in CIMMYT germplasm with as few as 1300 SNP markers (J Crossa, unpublished data). CIMMYT has links with the laboratory of E. Buckler (Cornell University, USA) to apply new, state-of-the-art genotyping by sequencing (GBS) methods to permit rapid-cycle genomic selection in its African breeding programs, beginning in 2010. High-density, low-cost markers allow the application of GS in multi-parent populations with better prospects for long-term gains than bi-parental populations. CIMMYT and IITA breeders are assembling multi-parent populations for this purpose. An innovative “open-source” breeding system has been planned that will permit smaller NARS and commercial breeding programs to use these tools to increase gains. These systems rely heavily on low-cost tissue sampling and DNA extraction; simple dry-seed chipping systems have been successfully implemented by CIMMYT and IITA and are ready to be shared with partners.

Why international agricultural research?
The new tools that are transforming commercial plant breeding in developed countries are not currently accessible to national research and extension systems and small- and medium-sized seed companies in the developing world, because their effective use requires strong capacity in biometrics, bioinformatics, high-density genotyping and doubled haploid systems. Few national systems or small companies have the needed depth of capacity in all these fields. Currently, only the largest multinational seed companies have been able to integrate these elements effectively into a product development pipeline.

Multinational seed companies consider their integrated molecular breeding pipelines highly proprietary. While they are increasingly open to collaboration with the CGIAR, they usually restrict the sharing of their technologies with third parties. They also cannot be relied on to deliver the products of these pipelines to the developing world where small and fragmented markets and low purchasing power of poor smallholders make breeding investments commercially unattractive. CIMMYT and IITA are public institutions with strong breeding, biometrics, and genetics capacities, and close links to both advanced research institutes and national research and extension systems. In collaboration with the GCP, they are well-placed to merge the new genotyping, phenotyping, informatics, and DH systems into an integrated public platform attuned to the needs of national systems and small- and medium-sized companies engaged in maize breeding.

Association mapping panels consisting of inbred lines with adaptation to all major tropical and subtropical target mega-environments have been assembled at CIMMYT for the specific purposes of detecting genes with effects on drought tolerance, disease resistance, and tolerance to infertile soils (Lu et al. 2009; Yan et al. 2009). These panels have been or are being phenotyped for many different traits in a wide range of environments and phenotyping systems; they are a unique, freely available resource for the maize research community and their value increases as they are phenotyped for more traits and in more environments.

CIMMYT and IITA provide the natural platform for linking small and technologically isolated NARS and small private sector breeding programs into “open-source” genomic selection networks, wherein a central breeding program cycles the selection populations, driving them towards improved allele frequencies on the basis of selection for genotype only; they also provide high-precision phenotyping in managed stress screens. By contrast the commercial and NARS “hubs” provide phenotyping for the training population in the target environment, and receive unique, genotyped proprietary DH lines pre-selected on the basis of GEBV for adaptation, stress tolerance, and yield potential in their own target markets. Only CIMMYT and IITA, in the public sector, have the international mandate and linkages, germplasm, and bioinformatics and biometrics capacity to implement such networks.

Researchable issues

- Optimizing marker-assisted recurrent selection (MARS) and genomic selection (GS) systems, in particular for multiple complex traits (e.g. yield potential, drought tolerance, mycotoxin resistance) that are essential in many tropical maize-growing environments, including:
  - Analyzing the power of high-density haplotype indices to predict phenotypic performance for multiple complex traits.
  - Translating reduced cycle time of MARS/GS into increased gains in stress-prone environments.

    - Generating predictive power of haplotype effects in one breeding program and sample of environments for the same allele in other similar populations and environments.
- Collaborative breeding models that integrate DH technology and rapid-cycle genomic selection to deliver unique, marketable inbreds and accurate performance predictions to breeders in national research and extension systems and small- and medium-sized companies, and that integrate the phenotyping capacity of national systems and such companies into model training.
- Proof of concept for rapid-cycle marker-based selection doubling breeding gains for quantitative traits in stress-prone environments.

Outputs

1. Low-cost statistical and software tools to quantify and adjust for field variation to improve the accuracy of both conventional and marker-assisted breeding.
2. Doubled haploid breeding systems for cultivar development programs of national research and extension systems and small- and medium-size seed companies.
    - Publically available tropical inducer lines with high (>8%) rates of induction.
    - Improved marker systems that allow increased recovery of haploid plants in diverse germplasm.
    - Haploid plant management and chromosome doubling strategies permitting high rates of DH recovery.
3. Low-cost, high-throughput tissue sampling and DNA extraction systems allowing small breeding programs to benefit from the high-density genotyping revolution.
4. State-of-the-art breeding and genotypic information management systems, permitting use of high-density marker information to increase breeding gains.
    - User-friendly system for the management of pedigree, phenotypic and genotypic information in molecular breeding, including DNA and tissue sample tracking for high-throughput genotyping.
    - Molecular breeding decision support tools integrated with informatics system for use in gene/trait-based marker-assisted selection, marker-assisted recurrent selection and genome-wide selection.
5. CIMMYT's association mapping panels, consisting of 500 inbred lines with adaptation to all major tropical and subtropical target mega-environments, assembled into a single, large, publicly available panel and genotyped at high density using both the new SNP50 array and the Cornell GBS platform; genotypic and phenotypic data assembled into a single public database, with seed and data freely available to the international maize research community for further phenotyping and client-specific gene discovery.
6. Proof-of-concept that rapid-cycle marker-based selection for quantitative traits at least doubles gains from selection per year in stress-prone environments.
7. "Open-source" breeding models that link breeding programs of national systems and small- and medium-sized seed companies with CIMMYT and IITA phenotyping and genomic selection networks for the delivery of proprietary DH lines, genotypic information, and predictions of performance under local conditions. This approach allows companies to select adapted proprietary germplasm with a high degree of confidence, even if their phenotyping capacity is limited. In return companies will feed phenotypic data back into public selection models used to advance elite populations used as sources for commercial products.
8. High-throughput low-cost phenotyping systems for component traits that increase selection gains for abiotic and biotic stress tolerance, water and nutrient use efficiency—such as biomass development, plant temperature, plant water status and root characteristics.

Research and development partners

New breeding tools will be refined via collaboration between CIMMYT, IITA, leading advanced research institutes, and selected national research systems and seed companies. The doubled haploid tropical inducer and system development is being done in collaboration with the University of Hohenheim. Genomic selection, high-density genotyping, and high-throughput DNA extraction protocols will be developed and implemented in collaboration with Cornell University. Sequencing of AM panel resources will be done in collaboration with the Beijing Genomics Institute. Clients for the outputs of this initiative include NARSs and SMEs with applied maize breeding programs in the developing world.

Outcomes

- Improved tools in use by a minimum of 15 national research and extension systems and small- and medium-sized companies in Africa, Latin America, and Asia.
- Accelerating breeding gains in breeding programs of national research and extension systems and small- and medium-sized companies.

Key milestones

2011: Needs assessment of capacities of national research systems and small- and medium-sized companies; definition of the specifications for maize breeding tools with highest return to investments given program size and education level.
2011: CIMMYT association mapping populations genotyped at high density; seed increased and single database established.
2011: Multi-parent synthetics initiated for GS proof-of-concept experiments.
2012: Integrated breeding program information management system completed and shared with partners.
2012: Field variability measurement systems validated and used to reduce error variation in phenotyping by CIMMYT, IITA and national research systems.
2013: High-throughput tissue sampling and DNA extraction systems developed/assessed and information shared with partners.
2013: Tropical haploid inducer with induction rate of >8% developed and shared with partners.
2013: MARS proof-of-concept experiments completed and gains from selection estimated.
2014: Confirmation of predictive power of breeding values estimated from high-density genotypes.
2014: Bioinformatics pipeline for high-density GBS marker data completed and shared with partners.
2014: High-throughput phenotyping systems validated for their ability to increase genetic gains and incorporated into CIMMYT and IITA breeding programs.
2015: GBS in routine use to genotype all fixed lines from the CIMMYT/IITA breeding programs at high density.
2015: "Open-source" molecular breeding programs deliver unique, genotyped DH lines to participating national research systems and companies, who return phenotypic data for model adjustment.
2016: First cycle of CIMMYT genomic selection completed and progress estimated.
2016: AM panel lines sequenced.

Linkages to other SIs

SI 9 will deliver enabling tools and technologies for use in all breeding objectives stated under SIs 4–7, and conduct proof-of-concept research within the breeding programs. The doubled-haploid system developed under this initiative will serve SI 4, SI 5, SI 6, and SI 7 in rapidly developing high-potential lines with new combinations of biotic/abiotic stress tolerance and nutritional quality. The effectiveness of genomic selection will be initially validated in SI 4 breeding programs targeting drought-prone and low-fertility systems in Eastern Africa. GBS will be applied to genotype at high density all fixed lines generated from CIMMYT and IITA breeding programs within the first three years of the CRP, and also will be the primary genotyping tool for LD mapping in CIMMYT association mapping populations, and in identifying novel alleles in CIMMYT's germplasm collection.

What's new in this initiative?

- This initiative will provide the first publicly available tropical haploid inducer lines to maize breeders worldwide.
- State-of-the-art public tools applicable in the context of breeding programs of NARS and local seed companies.
- The first application of genotyping by sequencing to public maize breeding programs, and the first proof-of-concept of rapid-cycle genomic selection will occur in CIMMYT's and IITA's African-targeted programs.
- Novel "open-source" designs for integrating rapid-cycle genomic selection and DH technology in SME and NARS breeding programs.

Targets and impact estimates

Assuming that genetic gains will only be increased by 25% (100% in temperate environments) from a current average yield of 3.4 t/ha for maize in the developing world, yields of products developed through use of these tools will be increased by approximately 0.25 t/ha relative to conventionally bred materials. If, starting 2020, annually an additional 1% of the adopted (sub-)tropical maize area is planted to varieties developed with these new tools, approximately 5.5 million tons of maize would be added annually (and increasing) to global maize production by 2030.

Other issues

Gender

The tools developed in this initiative are gender neutral. However, at least 50% of the clients engaged in testing of the new tools will be women scientists and young researchers from the target developing countries.

Capacity building

Only a handful of today's cadre of breeders in the developing world has been trained in the use of new tools envisioned in SI 9. Achieving the promise of the new breeding technologies will require substantial capacity building in NARS and private-sector breeding programs, and a new conceptualization of the role of molecular breeders, who will need to reduce their focus on genotyping and to increase their skills in quantitative genetic analysis and data management. This will require formal, intensive, multi-stage mid-career short-course training, supported by high-quality web-based training materials. Implementation of doubled-haploid technology and advanced phenotyping systems will be supported, both by short courses and by season-long training visits to CIMMYT to participate in all steps in the process.

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Strategic Initiatives 1–9. Summary investments in strengthening capacities in the maize value chain

Value proposition

Improve the capacity of women and men maize researchers, research organizations, and seed producers, thereby empowering and motivating them to provide relevant products and services for developing-country farmers—who must help double global food supplies while facing climate change effects and using fewer resources.

Estimated impact	
Increased numbers of scientists and technicians trained	100 scientists, technicians and partners in development, 20 MSc and 10 PhD students finish training per annum.
Benefits to the poor	*Direct:* Improved access to the knowledge of new technologies through strengthened partners in development (NGOs, CBOs, extension systems). *Indirect:* New higher-yielding varieties, resistant/tolerant to biotic and abiotic stresses and with enhanced nutritional quality, developed and disseminated faster through a well trained and well equipped network of maize researchers.
Empowering resource-poor women farmers	At least 25,000 resource-poor maize farmers, especially women, shall be trained in at least 10 target developing countries, through national research systems, CBOs, and NGOs, in improved maize technologies/practices—leading to sustainable and enhanced maize production.
Benefits to the environment	Agronomists, breeders, and partners in development trained in the use of conservation agriculture principles and modern breeding tools to enable sustainable intensification of maize production in developing countries.
Others	Strengthening of national research systems to increase the quality of data generated by the global maize breeding and agronomy networks, in turn leading to better quality data sets and more precision in selecting varieties and making management recommendations.

Justification

General background

Based on a recent analysis by the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB) of the Food and Agriculture Organization of the United Nations (FAO 2005), capacities in both conventional and modern plant breeding technologies in many developing countries are insufficient to fully capture the benefits of international collaboration, new tools, and technologies, or to assure the food security of a world population that is projected to double by 2050. A major constraint to maize research for development in public institutions of many developing countries is the insufficient number of skilled, well-prepared scientists and technicians. The new generation of agronomists, breeders, and associated social scientists in developing countries should be equipped not only with multidisciplinary theoretical backgrounds but also with practical field experience. They require this experience to conduct applied breeding programs and agronomic research that leverages the power of modern crop science to develop sustainable, productive, profitable and socially acceptable varieties and cropping systems for resource-poor farmers in the developing world.

Despite a rapid increase in the number of seed companies in many countries (Langyintuo et al. 2008)—a substantial number of which register and produce hybrid varieties derived from CIMMYT and IITA—the output of hybrid seed in such emerging companies is typically less than 100–300 tons per year, with high failure rates in both their seed multiplication activities and as businesses. Applied technical knowledge and business management skills need to be strengthened to increase scale-up and success rates. Likewise, training and partnerships with small- and medium-sized agricultural machinery manufacturers can stimulate local development and marketing of suitable and affordable conservation agriculture implements.

Multiple partners from both public and private sectors will need to collaborate to realize the goals of strengthening agriculture-related research, also crop and seed production capacity, in Africa, Asia, and Latin and South America. Resource-poor farmers, especially women, require training in partnership with local institutions and organizations, to unleash the full potential of new varieties and knowledge-intensive crop management practices on their homesteads. Strengthening the capacity of partners in development (international centers, national research and extension systems, seed companies, NGOs and CBOs, and farmers associations) to facilitate researcher-farmer and farmer-to-farmer information flows is a crucial prerequisite to strengthening crop and seed production capacity in much of the developing world.

Beyond enabling a new generation of scientists and other professionals to work in partnership with the CGIAR, the private sector, policy makers and other stakeholders, and to make optimal use of international research products, knowledge, data sets, extension and learning materials resulting from implementing the strategic initiatives, MAIZE must also be available to the public in client-oriented open access arrangements (primarily through internet based applications).

Why international agricultural research?
International centers like CIMMYT and IITA have established strong strategic partnerships with national research systems, other international centers, the private sector, universities, advanced research institutes, and NGOs. Their long regional histories, support of a multi-disciplinary research approach, and solid reputation of providing high quality and practical training to maize scientists and technicians—many of whom now teach in regional universities or hold leadership positions in the national research systems—all testify to the importance of continued international center involvement in capacity building within developing countries. Many MAIZE research products are highly specialized and knowledge-intensive, and can only be transmitted through interactive partnerships that include significant training components. As an example, efficient data management and analysis in crop management and breeding research increasingly require training-intensive IT tools that store, integrate, analyze, display and permit the utilization of complex data sets—including pedigree information, trait and molecular data, GIS and spatial data, as well as biometric and simulation tools. The international centers play a key role in making available the tools themselves and the training to utilize them effectively.

Outputs

1. At least three training modules developed every year and made accessible (e.g. as e-learning) to the maize scientific community in sub-Saharan Africa, South Asia and Latin America in areas such as:
    - Maize value chains, policy, and market analysis; technology targeting, upscaling, and impact analysis (SIs 1, 2, 7, 8).
    - Principles and practice of conservation agriculture in maize-based farming systems; integrated disease and insect-pest management; integrated nutrient management (SI 3).
    - Conventional and molecular breeding and pathology (including markers and transgenics, high-throughput phenotyping, trial and nursery management) (SIs 4, 5, 6, 7, 8).

- Techniques of good quality seed production; seed business management; seed certification (SIs 4, 5, 6, 7).
- Region-appropriate biosafety protocols and regulatory frameworks (seed certification, DNA fingerprinting, screening maize pests/pathogens) (SIs 4 and 5).
- Post-harvest problems, mycotoxin contamination, and post-harvest technological interventions (SI 6).
- The effective and beneficial conservation of genetic resources (SI 8).
- Data management and analysis; biometric analyses and simulation of breeding methodologies (SIs 8, 9).

2. An international maize improvement network of researchers, focused on sharing information and knowledge about maize and strengthening continuous professional development of maize professionals including university professors.
3. International, regional and in-country training courses targeted at 50 young and mid-career maize scientists (and related disciplines) annually.
4. At least 30 personnel from national research systems, the private sector, NGOs and CBOs trained in seed production and seed systems annually.
5. At least 20 MSc and 10 PhD students conduct their research towards their MSc/PhD degrees under guidance of CIMMYT and IITA scientists every year.
6. National agricultural research and extension systems, community-based organizations, non-governmental organizations and local seed companies supported to train at least 25,000 farmers, especially resource-poor women, as part of SI 2.
7. Diverse extension materials (fact sheets, posters, bulletins, radio and video scripts and files, others), methodologies, and decision-making support tools developed, utilized, and made accessible in centralized online repository for effective and impactful dissemination of information and knowledge on important aspects—including for example in-situ conservation of genetic resources, community-based seed production, post-harvest management and conservation agriculture.
8. Knowledge, information and data resulting from research-for-development activities managed and shared in several web-based applications, including databases, portals, communication platforms, repositories and websites.

Research and development partners

International agricultural research centers (CIMMYT, IITA), FAO (through GIPB), advanced research institutes, leading regional institutions/universities in national research systems (India, China, Brazil, Mexico, Nigeria, and Ghana), public and private seed and other agriculture-related companies (e.g. molecular laboratories).

Development partners capable of utilizing and up-scaling capacity-building outputs include: maize programs within national research systems, international centers (CIMMYT, IITA), FAO, advanced research institutes, private industry, trade associations, community based organizations and national and international NGOs.

Outcomes

- Increased capacity of partner institutions to introduce, adapt and use new tools and methods, and increased efficiency in developing new maize varieties with abiotic and biotic stress tolerance/resistance and improved nutritional quality.
- Enhanced regulatory and technical capacity of authorities in 10+ developing countries, raising their awareness on transgenics and biosafety and fostering more efficient certification of new varieties.

- Increased capacity of partner institutions to conduct adaptive agronomy research that applies the principles of conservation agriculture.
- Strengthened professional capacity of national agricultural research and extension systems, emerging seed companies, nongovernmental organizations and community-based organizations to undertake and promote production of quality maize seed.
- Strengthened professional research capacity of national agricultural research and extension system partners to design and manage sustainable, efficient long-term maize breeding programs and agronomy research.
- Enhanced plant breeding curricula at universities and other educational institutions in target developing countries.
- Strengthened regional and global networks of maize scientists, and international collaboration among research and academic institutions.
- Improved and updated biosafety regulations in place in more than 10 developing countries.

Key milestones – annual

- Infrastructure (enabling increased efficiency in developing new maize varieties with abiotic and biotic stress tolerance/resistance and improved nutritional quality) strengthened/established in two target countries each year for implementing the MAIZE research agenda in SIs 4–8.
- At least three learning modules/materials developed annually in key areas of maize research-for-development, using diverse formats (including multimedia) and made publicly available.
- At least five in-country/regional courses and two international courses conducted annually for training at least 150 researchers from national agricultural research and extension systems, the private sector, and other stakeholders.
- At least three technological packages (multi-format extension materials) developed every year.
- Development partners from NGOs, CBOs, farmer associations and other entities updated annually/biannualy on new technologies available for massive dissemination.
- Regulatory and technical capacity of at least two developing countries improved annually.

Other issues

Gender

Given the inadequate number of women in agricultural sciences, in particular in postgraduate and higher positions, and also that many national research system scientists are close to retirement, this SI will have a distinct gender focus, and strive to proactively foster the participation of women and young professionals in MAIZE capacity-strengthening activities.

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Annex 1. Population, poor and maize area in rainfed farming systems with more than 1 million hectares of maize. Data are based on farming systems described by Dixon et al (2001), Hyman et al. (2008), and poverty data from Wood et al. (2010) and crop distribution maps from You et al (2000; accessed 2009). Proportaion data of maize area in farming systems not inlcuded by Hyman et al (2008) was estimated based on FAO country data.

Farming system	Farm type	Total Pop (million)	Rural Pop (million)	Urban Pop (million)	Stunted children (million)	Prevalence Stunting (%)	Drought Probability	Cultivated area affected by drought PDIIc	Maize area (million ha)	Poor in farming system area (million)	Poor in maize area (million)	Proportion poor in farming system	"Maize-dependent" poor (million)	Prop maize area	Rank of maize area among crops	Most important crop by area
Source of data	*Dixon et al. 2001*	*Hyman et al (2008)*	*Hyman et al (2008)*	*Hyman et al (2008)*	*Hyman et al (2008)*	*Hyman et al (2008)*	*Hyman et al (2008)*	*Hyman et al (2008)*	*You et al (2009)*	*Wood et al (2010)*	*Wood & You*	*Wood et al (2010)*		*Several sources*	*Hyman et al (2008)*	*Hyman et al (2008)*
Asia - tropical and subtropical maize																
Highland extensive mixed EAP	Smallholder	64	52	12	2.5	44%	10%	682,635	1.3	22.9	16.8	36%	13.2	14%	2	Rice
Lowland rice EAP	Smallholder	786	496	290	13.4	34%	8%	7,963,917	7.7	145.1	119.0	18%	96.3	17%	2	Rice
Upland intensive mixed EAP	Smallholder	502	359	144	15.4	35%	11%	3,725,591	8.2	106.9	82.1	21%	114.2	27%	1	Maize
Highland mixed SA	Smallholder	86	66	20	5.2	48%	12%	827,142	1.8	36.9	27.1	43%	28.9	20%	3	Rice
Rainfed mixed SA	Smallholder	357	249	107	24.5	63%	17%	8,176,456	3.2	185.1	168.4	52%	48.9	7%	7	Rice
Rice–wheat SA	Smallholder	491	365	126	28.3	52%	35%	4,050,261	2.9	278.6	203.6	57%	112.6	10%	5	Rice
Latin America - tropical and subtropical maize																
Cereal-livestock (Campos) LAC	Dualistic	23	9	14	0.2	9%	12%	1,179,115	2.6	2.0	1.6	9%	1.6	14%		
Coastal plantation mixed LAC	Dualistic	123	40	82	1.7	19%	7%	1,841,622	3.7	18.3	14.1	15%	14.1	13%		
Dryland mixed LAC	Smallholder	25	9	16	0.7	19%	27%	897,951	2.2	4.3	3.0	17%	3.0	21%		
Extensive dryland mixed (Gran Chaco) LAC	Dualistic	5	1	4	0.1	16%	65%	106,230	2.7	0.5	0.4	10%	0.4	6%		
Intensive highland mixed (N. Andes) LAC	Smallholder	39	9	29	0.4	16%	6%	281,978	3.7	7.1	3.6	18%	3.6	11%		
Irrigated	Dualistic								2.5	2.5	1.3		1.3	13%		
Maize–beans (Mesoamerica) LAC	Smallholder	76	29	47	2.8	37%	16%	1,218,125	4.5	5.5	4.5	7%	5.5	67%	1	Maize
Sub-Saharan Africa - tropical and subtropical maize																
Agro-pastoral millet/sorghum SSA	Smallholder	55	38	17	3.1	37%	53%	2,633,259	1.2	38.8	24.5	71%	10.1	7%	5	Millet
Cereal-root crop mixed SSA	Smallholder	84	69	15	6.3	43%	17%	5,331,317	4.0	63.8	48.7	76%	31.9	13%	4	Sorghum
Forest based SSA	Smallholder	43	28	15	3.2	37%	3%	1,029,787	1.4	32.2	10.6	75%	5.3	14%		
Highland temperate mixed SSA	Smallholder	43	37	7	2.8	50%	18%	909,683	1.1	21.7	19.1	50%	21.8	25%	1	Maize
Large commercial–smallholder SSA	Dualistic	34	12	22	0.9	23%	67%	520,323	3.5	10.9	5.7	32%	5.7	26%	1	Maize
Maize mixed SSA	Smallholder	97	73	24	6.3	43%	24%	2,535,536	6.1	62.9	40.4	65%	62.9	46%	1	Maize
Root crop SSA	Smallholder	70	47	23	5.0	40%	8%	1,802,876	3.3	61.6	36.9	88%	67.8	28%	1	Maize
Tree crop	Smallholder								1.8	27.4	17.4		8.7	17%		
Temperate maize																
Temperate mixed EAP Smallholder rainfed hum	Smallholder	261	139	122	2.6	26%	20%	849,686	11.9	42.7	39.7	16%	42.7	53%	1	Maize
Pastoral EAP	Pastoral								1.3	18.6	10.9		5.4	6%		
Large scale cereal-vegetable EECA Dualistic	Dualistic	66	28	37	0.3	16%	3%	623,956	2.2	1.7	1.0	3%	1.0	3%		
Temperate mixed (Pampas) LAC Dualistic	Dualistic	29	3	25	0.2	13%	33%	1,446,738	2.4	1.2	0.7	4%	0.4	8%		
Summary by region			*More than*					*More than*								
East and South-East Asia		1,352	907	446	31	35%		12,372,143	17.2	275	218	20%	224			
South Asia		934	680	253	58	56%		13,053,859	7.9	501	399	54%	190			
Latin Amercia		291	97	192	6	22%		5,525,021	11.3	40	29	14%	30			
Sub-Saharan Afrcia		426	304	123	28	40%		14,762,781	18.8	319	203	75%	214			
Temperate		356	170	184	3	23%		2,920,380	17.8	64	52	18%	49			
Summary by farmer group			*More than*					*More than*								
Smallholder systems >15% drought		1,185	832	352	72.2	41%		24,842,905	24.0	639	493	54%	275			
Smallholder systems <15% drought		1,695	1,114	581	48.7	42%		18,144,420	32.1	471	340	28%	367			
Dualistic farming systems		480	212	265	5.2			5,646,859	31.0	89	68	19%	66			
Total		**3,359**	**2,158**	**1,198**	**126**			**48,634,184**	**87.1**	**1,199**	**901**		**707**			

Annex 2. Partner consultations and current partners of MAIZE (abridged[15])

MAIZE builds up on the input, insights, and collaboration with over 342 (179) partners, including from 129 (70) national agricultural research systems (NARS), 18 (6) regional and international organizations, 21 (4) advanced research institutes (ARIs), 75 (38) universities, 46 (22) private sector organizations, 42 (4) non-governmental organizations and farmer cooperatives, and 11 (10) host countries of MAIZE offices, listed below. Values in parentheses indicate the number of organizations that currently also receive funding through CIMMYT- and IITA-managed activities, and which denote highly-formalized interactions.

The choice and design of individual Strategic Initiatives further benefited from recent stakeholder consultations in the frame of

- The concerted efforts of CIMMYT, IITA, GCP, AATF and Monsanto on drought-tolerant maize in Africa and Asia, and associated farmer surveys and consultations (2006/2009)
- The Latin America Maize Breeding Consortium (CIMMYT, 2008/2009)
- The Asia Hybrid Maize Breeding Consortium (CIMMYT and APSA, 2009)
- The Sustainable Intensification of Legume Systems in eastern and southern Africa program which was defined in consultation with eastern and southern African NARSs and ASARECA (ACIAR, CIMMYT and ICRISAT, 2009/2010)
- Recent consultations with various governments that resulted in the redefinition of workplans and new MoUs, including the Government of India (ICAR-CIMMYT 2009–2012 Workplan), Indonesia (2009, MoU), China (2009, MoUs with several institutions) and Mexico (2009/2010, new MoU forthcoming)
- Large number of recent 1:1 consultations with partner countries and advanced research capacities in the public and private sector

The draft version of MAIZE was shared through email with close to 500 individuals in over 350 institutions and highly valuable feedback received, incorporated, and summarized (https://sites.google.com/a/cgxchange.org/maize/home). The draft version was also shared and discussed through side events at meetings such as the ASARECA Board Meeting, the Asia Maize Hybrid Consortium Meeting, and meetings with individual NARS in Cambodia, Ethiopia, India, Indonesia, Laos, and Mexico. These consultations are continuing and feedback incorporated in the implementation of MAIZE.

National Agricultural Research Institutes

Angola, Instituto de Investigação Agronómica (IIA)
Argentina, Instituto Nacional de Tecnología Agropecuaria (INTA)
Azerbaijan, Institute of Genetic Resources
Bangladesh, Bangladesh Academy for Rural Development
Bangladesh, Agricultural Research Council (BARC)
Bangladesh, Rangpur-Dinajpur Rural Services
Bangladesh, Bangladesh Agricultural Research Institute (BARI)
Bangladesh, Bangladesh Rice Research Institute
Benin, Institut National de Recherche Agronomique du Benin (INRAB)

[15] This list may unintentionally exclude donor stakeholders, and participants involved in the International Maize Improvement Networks. We also apologized for any inadverted omission and appreciate such omission being highlighted to us.

Bolivia, CIF
Botswana, Department Agricultural Research
Bulgaria, Institute of Plant Genetic Resources "K. Malkov"
Burkina Faso, Equipe de Recherche du Burkina Faso (INERA)
Burkina Faso, Institut de l’Environnement et de Recherches Agricoles (INERA)
Burkina Faso, Ministère de l’Agriculture
Burundi, Institut des Sciences Agronomiques du Burundi (ISABU)
Cameroon, Ches Agricoles pour le Developpement
Chad, Institut Tchadien de Rescherches Agricoles pour le Developpement
China, Chinese Academy of Agricultural Science
China, Guangxi Academy of Agricultural Science
China, Guizhou Academy of Agricultural Science
China, Sichuan Academy of Agricultural Sciences
China, Yunnan Academy of Agricultural Sciences
Colombia, Corporación Colombiana de Investigación Agropecuaria (CORPOICA)
Costa Rica, Instituto Nacional de Innovación Tecnológica en Agricultura (INTA)
D.R. Congo, Institut National Pour I'Etude et la Recherche Agronomique
D.R. Congo, N'Senga Lutanga Farm
D.R. Congo, National Service of Seed
DPR Korea, Crop Genetic Resources Institute
El Salvador, Centro Nacional de Tecnologia Agropecuaria y Forestal (CENTA)
Ethiopia, Ethiopia Institute of Agricultural Research (EIAR)
Ethiopia, Ethiopian Seed Enterprise
Ethiopia, Ethiopian Health and Nutrition Research Institute (EHNRI)
Ethiopia, Ministry of Agriculture and Rural Development (MoARD)
Ethiopia, Oromia Seed Enterprise (OSE)
Georgia, Georgian Institute of Farming, Field Crops PGR
Ghana, Council for Scientific and Industrial Research (CSI R)
Ghana, Crop Research Institute (CRI)
Ghana, Ghana Grains and Legumes Development Board
Ghana, Ministry of Food and Agriculture
Ghana, Savannah Agricultural Research Institute (SARI)
Guatemala, Instituto de Ciencia y Tecnologia Agricola (ICTA)
Guinea, Institut de Recherches Agronomique de Guinee
Honduras, Direccion de Ciencia y Tecnologia Agricola (DICTA)
Honduras, EAPEZ
India, Directorate of Maize Research (DMR)
India, WB Department of Agriculture
India, Indian Council of Agricultural Research (ICAR)
India, Indian Agricultural Research Institute
Indonesia, Indonesian Center for Agricultural Biotechnology and Genetic Resources Research and Development (ICABIOGRAD), Indonesia
Indonesia, Indonesian Center for Food Crops Research for development (ICFORD)
Iran, Agricultural Biotechnology Research Institute of Iran (ABRII)
Iran, Agricultural Engineering Research Institute (AERI)
Iran, Agricultural Research, Education and Extension Organization (AREEO)
Iran, Dryland Agricultural Research Institute (DARI)
Iran, Iranian Research Institute for Plant Protection (IRIPP)

Iran, Seed and Plant Improvement Institute (SPII)
Iran, Soil and Water Research Institute (SWRI)
Ivory Coast, Centre National de Recherche Agronomique
Ivory Coast, Fonds Interprofessionnel Pour La Recherche et le conseil Agricoles
Ivory Coast, Ministère de l'agriculture
Kenya, Kenya Agricultural Research Institute (KARI)
Kenya, Kenya National Biosafety Authority
Kenya, Kenyan Plant Health Inspectorate Service (KEPHIS)
Lesotho, Department of Agriculture Research
Lesotho, Ministry of Agriculture and Food Security
Malawi, Department of Agricultural Extension
Malawi, Department of Agricultural Research Services
Malawi, Ministry of Agriculture
Mali, Institut d'Economie Rurale (IER)
Mexico, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV)
Mexico, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP)
Mexico, FIRA
Mexico, Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion
Mexico, Universidad Autonoma Metropolitana (UAM)
Mozambique, CLUSA
Mozambique, Institute Investigacao Agricao Mozambique (IIAM)
Mozambique, Instituto Superior Politecnico de Manica
Nepal, Agriculture Botany Division, Nepal Agricultural Research Institute
Nepal, Nepal Agricultural Research Council (NARC) including the National Maize Research Program
Nicaragua, Instituto Nicaraguense de Tecnologia Agropecuaria (INTA)
Nigeria, Agriculture Department of Bwari Area Council
Nigeria, Institute of Agricultural Research (IAR)
Nigeria, National Agency for Food and Drug Administration and Control (NAFDAC)
Nigeria, National Agricultural Sample Census Pilot (NASC)
Nigeria, National Agricultural Extension, Research and Liaison Services (NAERLS)
Nigeria, National Center for Genetic Resources & Biotechnology
Pakistan, Maize and Millet Research Institute
Panama, Instituto de Investigacion Agropecuaria de Panama (IDIAP)
Paraguay, Centro Regional de Investigacion Agricola (CRIA)
Peru, Instituto Nacional de Innovacion Agraria (INIA)
Peru, Ministry of Agriculture
Philippines, Institute of Plant Breeding (PCARRD)
Russia, Vavilov Institute of Research
Rwanda, Institut des Sciences Agronomiques du Rwanda (ISAR)
Senegal, Fondation Agir pour l'Education et la Santé (FAES)
Senegal, Institut Senegalais de Recherches Agricoles
Senegal, Plant Protection and Quarantine Services (SPV)
Senegal, Université de THIES
Sierra Leone, Sierra Leone Agricultural Research Institute
South Africa, Agricultural Research Council including the Grain Crops Institute
South Africa, Department of Agriculture
Sri Lanka, Plant Genetic Resources Centre (PGRC)
Sudan, Agricultural Research Corporation (ARC)

Swaziland, Ministry of Agriculture including Malkerns Research Station
Swaziland, Ministry of Agriculture, Cereals Promotion and Extension
Swaziland, National Plant Genetic Resources Centre (NPGRC)
Tanzania, BRAC
Tanzania, Commission for Science and Technology (Costech)
Tanzania, Ministry of Agriculture
Tanzania: Agriculture Research Institutes including the Chollima Research Center, the Mikocheni Agricultural Research Institute (MARI); the Selian Agricultural Research Institute (SARI)
Tanzania: National Plant Genetics Resources Center
Thailand, Department of Agriculture including the Nakhon Sawan Field Crops Research Center
Togo, Institut Togolais de Recherches Agricole
Uganda, Mukono Zonal Agricultural Research for Development Institute (ZARDI)
Uganda, National Agricultural Research Organization (NARO)
Uganda, National Crops Resources Research Institute
Uruguay, Instituto Nacional de Investigación Agropecuaria (INIA)
Uruguay, Universidad de la República (UdelaR)
Uzbekistan, Uzbek Research Institute of Plant Industry (UzRIPI)
Vietnam, National Maize Research Institute
Yemen, Agricultural Research & Extensions Authority (AREA)
Zambia, Ministry of Agriculture and Co-operatives
Zambia, National Plant Genetic Resources Centre (NPGRC)
Zambia, Seed Control Certificate Services
Zambia, Zambia Agricultural Research Institute (ZARI) including the Zambia Agricultural Research Institutes at Choma and Mt Makulu
Zimbabwe, Department of Agriculture and Extension
Zimbabwe, Genebank of Zimbabwe
Zimbabwe, Plant Protection Research Institute

Regional and International Organizations
Columbia, International Center for Agriculture in the Tropics (CIAT)
Costa Rica, Inter-American Institute for Cooperation on Agriculture (IICA)
Ghana, Forum for Agricultural Research for Africa (FARA)
Ethiopia, International Livestock Research Institute (ILRI)
India, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Italy, Central Advisory Service for Intellectual Property (CAS-IP)
Italy, Global Crop Diversity Trust
Kenya, the World Agroforestry Center (ICRAF)
Mexico, International Maize and Wheat Improvement Center (CIMMYT)
Nigeria, International Institute of Tropical Agriculture (IITA)
Peru, International Potato Center (CIP)
Philippines, International Rice Research Institute (IRRI)
Senegal, Conference of the agricultural research leaders in West and Central Africa (CORAF) / West and Central African Council for Agricultural Research and Development (WECARD)
Uganda, Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)
Uruguay, FORAGRO
USA, International Food Policy Research Institute (IFPRI)
Zimbabwe, Community Technology Development Trust (CTDT)

Advanced Agricultural Research Institutes

Australia, Queensland Dept of Employment, Econ Dev and Innovation (QDEEDI)
Australia, Commonwealth Scientific & Industrial Research Organization (CSIRO)
Brazil, CIRAD
Brazil, Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)
China, Beijing Genomics Institute (BGI)
China, Chinese Academy of Agricultural Sciences (CAAS)
France, Institute National de la Recherché Agronomique INRA
Germany, Max Planck Institute of Molecular Breeding
Hungary, Research Centre for Agrobotany
Italy, National Research Council—Institute of Sciences of Food Production (ISPA)
Kenya, African Agricultural Technology Foundation (AATF)
Netherlands, RIKILT—Institute of Food Safety
Netherlands, Plant Research International
Sweden, Nordic Gene Bank
UK, KBioscience
USA, Couger Patent Law
USA, Southern Regional Research Center-USDA-ARS
USA, US Department of Agriculture, Agricultural Research Services (USDA-ARS)
USA, USDA/ARS at University of Illinois
USA, USDA-ARS at University of Arizona
USA, USDA Foreign Agricultural Service (FAS)

Universities

Argentina, Buenos Aires, Universidad de Buenos Aires
Australia, Adelaide, Flinders University
Australia, Brisbane, University of Queensland
Australia, Perth, Institute for Crop and Plant Sciences (Faculty of Sustainability, Environmental & Life Sciences), Murdoch University
Austria, Tulln, University of Natural Resources and Applied Life Sciences (BOKU)
Belgium, Leuven, K.U. Leuven
Canada, Guelph, University of Guelph
Chile, Facultad de Ciencias Agrarias, Universidad Austral de Chile
China, Beijing, China Agricultural University
China, Sichuan, Sichuan Agricultural University
D.R. Congo, Lumbumbashi, University of Lumbumbashi
Ethiopia, Haramaya, Haramaya University
Ethiopia, Hawassa, Hawassa University
Germany, Freiburg, University of Freiburg
Germany, Goettingen, University of Goettingen
Germany, Stuttgart, University of Hohenheim
Ghana, Accra, University of Ghana—West Africa Centre for Crop Improvement (WACCI)
Ghana, Kumasi, University of Science and Technology
India, Karnal, Haryana Agricultural University
India, Koochbihar, UBKV (Uttarbanga Krish Vishvidyalaya)
India, Ludhiana, Punjab Agriculture University (PAU)

India, Meerut, Sardar Vallabah Bhai Patel University of Agriculture & Technology (SVBPUAT)
India, New Delhi, Acharya N.G. Ranga Agricultural University (ANGRAU)
India, Pusa, Bihar, Rajendra Agriculture University
India, Raichur, UAS
India, Samastipur, Rajendra Agricultural University (RAU), Pusa
India, Thanjavur, Tamil Nadu Agricultural University (TNAU)
India, Udaipur, Maharana Pratap University of Agriculture & Technology (MPUAT)
Italy, Piacenza, Università Cattolica del Sacro Cuore
Kenya, Nairobi, University of Nairobi
Lesotho, Roma, National University of Lesotho
Malawi, Lilongwe, Bunda College of Agriculture
Malaysia, Penang, Universiti Sains Malaysia
Mexico, Durango, Universidad Juárez del Estado de Durango
Mexico, Texcoco, Colegio de posgraduados
Mexico, Texcoco, Universidad Autonomo de Chapingo
Mexico, Torreon, Universidad Autonoma Agraria Antonio Narro Unidad Laguna
Mexico, Tuxtla Gutierrez, Chiapas, Instituto Tecnologico de Tuxtla Gutierrez, ITTG
Mozambique, Maputo, Eduardo Mondhlane University
Mozambique, Nampula, Lúrio University (UniLurio)
Netherlands, Wageningen, Wageningen University
Nicaragua, Universidad Nacional Agraria
Nigeria, Ado-Ekiti, University of Ado-Ekiti
Nigeria, Babcock, Babcock University
Nigeria, Ibadan, Institute of Agriclture, Research Training (IAR & T)
Nigeria, Ibadan, University of Ibadan
Nigeria, Ile-Ife, Obafemi Awolowo University (OAU)
Nigeria, Ilorin, University of Ilorin
Nigeria, Maiduguri, University of Maiduguri (UNIMAD)
Norway, Aas, University of Life Sciences
Peru, La Molina, Universidad Nacional Agrar (UNA)
Philippines, National Plant Genetic Resources Laboratory, Institute of Plant Breeding at the University of the Philippines Los Baños (UPLB)
South Africa, Pietermaritzburg, University of KwaZulu-Natal
Spain, Lleida, University of Lleida
Tanzania, Dar es Salaam, Sokoine University of Agriculture
Uganda, Kampala, Makerere University
UK, Leeds, Leeds University
USA, Ames, IA, Iowa State University
USA, Blacksburg, VA, University of Virginia
USA, Blacksburg, VA, Virginia Tech
USA, Champaign, IL, University of Illinois
USA, Davis, CA, University of California-Davis
USA, Knoxville, TN, University of Tennessee
USA, Lansing, MI, Michigan State University
USA, Madison, WI, University of Wisconsin
USA, New Jersey, Rutgers University
USA, New York, The Earth Institute at Columbia University
USA, New York, Cornell University

USA, North Carolina, North Carolina State University
USA, Oklahoma, Oklahoma State University
USA, Pittsburg, PA, Pittsburg University
USA, West Lafayette, IN, Purdue University
USA, Penn State University
Zambia, Lusaka, University of Zambia
Zimbabwe, Harare, Dept. of Agric. Engineering

Private Sector Organizations (22 funded/46 total)
D.R. Congo, Katanga Seed Producers Association
Ethiopia, Fafa Food S.C.
Ethiopia, Gadissa Gobena Commercial Farms PLC
Ethiopia, Seka Corn Flakes PLC
Ghana, A&B Seed Company
Ghana, Alpha Seed Company
Ghana, Nestle
Ghana, Savanna Seed Services Co.
India, Kridhidhan Seeds Ltd.
India, Syngenta India Limited
Kenya, Dryland Seed Co.
Kenya, East African Seed Co.
Kenya, Freshco Seeds
Kenya, Kenya Seed Co.
Kenya, Western Seed Co.
Mexico, AARSP
Mexico, AGROBIO
Mexico, Grupo Agro-empresarial Cresa
Mexico, Makala
Nigeria, Alheri Seed Co.
Nigeria, DA-ALLGREEN SEEDS
Nigeria, Dado Seeds
Nigeria, Maslaha Seed Co.
Nigeria, MOOR Plantation
Nigeria, Nestle (also in Cote d'Ivoire)
Nigeria, Premier Seed Co.
Nigeria, Savanna Seed and Livestock Ltd
Nigeria, Seed Project Co.
South Africa, PANNAR
Switzerland, Monsanto (also in Kenya, Mexico, South Africa, USA)
Switzerland, Syngenta
Tanzania, Aminata Quality Seeds and Consultancy Ltd
Tanzania, FICA Seeds (2002) Ltd
Tanzania, Meru Agro-Tours & Consultants Co. Ltd
Tanzania, Nyirefami Ltd
Tanzania, Suba Agro Trading and Engineering Co Ltd (SATEC)
Tanzania, TanSeed International
Uganda, Caii Seed Co.
Uganda, FICA Seeds

Uganda, NASECO Seeds 1996 Ltd
Uganda, Victoria Seed Limited (VS)
USA, BASF
USA, Pioneer Hi-Bred Intl.
Zambia, ZamSeed
Zimbabwe, AGRITEX
Zimbabwe, Seed Co (also in Zambia)

Non-Governmental Organizations and Farmers Cooperative Organizations
Angola, Catholic Relief Services (CRS)
Burkina Faso, Regional Agribusiness and Trade Promotion (ATP) Project, West Africa
Colombia, Bogota, Colombian Cereal Growers Association (FENALCE)
Colombia, Bogota, Colombian Palm Oil Growers Association (FEDEPALMA)
El Salvador, Catholic Relief Services (CRS)
Ethiopia, World Vision (WV)
Honduras, La Ceiba, Fundacion Investigacion Participativa con Agricultores de Honduras (FIPAH)
Kenya, Catholic Diocese of Embu
Kenya, Catholic Diocese of Homabay
Kenya, Catholic Relief Services (CRS)
Kenya, World Vision (WV)
Malawi, Seed Trade Association of Malawi
Malawi, Total Landcare
Malawi, World Vision (WV)
Mali, Comptoir
Mali, DNA
Mali, Fasokaba
Mexico, Salamanca, Gto., Agricultura Sostenible en Base a Siembra Directa, ASOSI D
Mexico, Mexico, D.F., Sistema Producto Maiz del D.F.
Mozambique, Chimoio, Manica Farmers Association
Nepal, ABTRACO-Kathmandu
Nepal, CeCRED-Parbat
Nepal, DIWO-Syangja
Nepal, DOS-Gorkha
Nepal, FORWARD-Chitwan
Nepal, KDF-Khotang
Nepal, LIBIRD-Pokhara
Nepal, RAS-Dang
Nepal, SAHAS-Okhaldhunga
Nepal, Support Foundation-Kanchanpur
Nepal, TTRI-Lalitpur
Nepal, TUKI-Sindhupalchowk
Nepal, UJBP-Arghakhanchi
Nepal, YMMC-Jajarkot
Nepal, International Development Enterprises
Nigeria, Commercial Agriculture Development Project
Switzerland, Syngenta Foundation for Sustainable Agriculture
Tanzania, Tanzania Participatory Nature Conservation Movement (TPNCM)
Zambia, Monze, Farmer Training Center

Zambia, Lusaka, Golden Valley Agricultural Research Trust
Zambia, Programme Against Malnutrition
Zimbabwe, Development Aid from People to People (DAPP)

Countries hosting MAIZE offices
Afghanistan, Kabul, Ministry of Agriculture
Bangladesh, Dhaka, Ministry of Agriculture
China, Beijing, Ministry of Agriculture
Colombia, Cali, International Center for Agriculture in the Tropics (CIAT)
Ethiopia, Addis Ababa, Ministry of Agriculture
India, Hyderabad, ICRISAT
Kenya, Nairobi, Ministry of Agriculture
Mexico, Texcoco, Ministry of Agriculture
Nepal, Kathmandu, Ministry of Agriculture
Nigeria, Ibidan, Ministry of Agriculture
Zimbabwe, Harare, Ministry of Agriculture

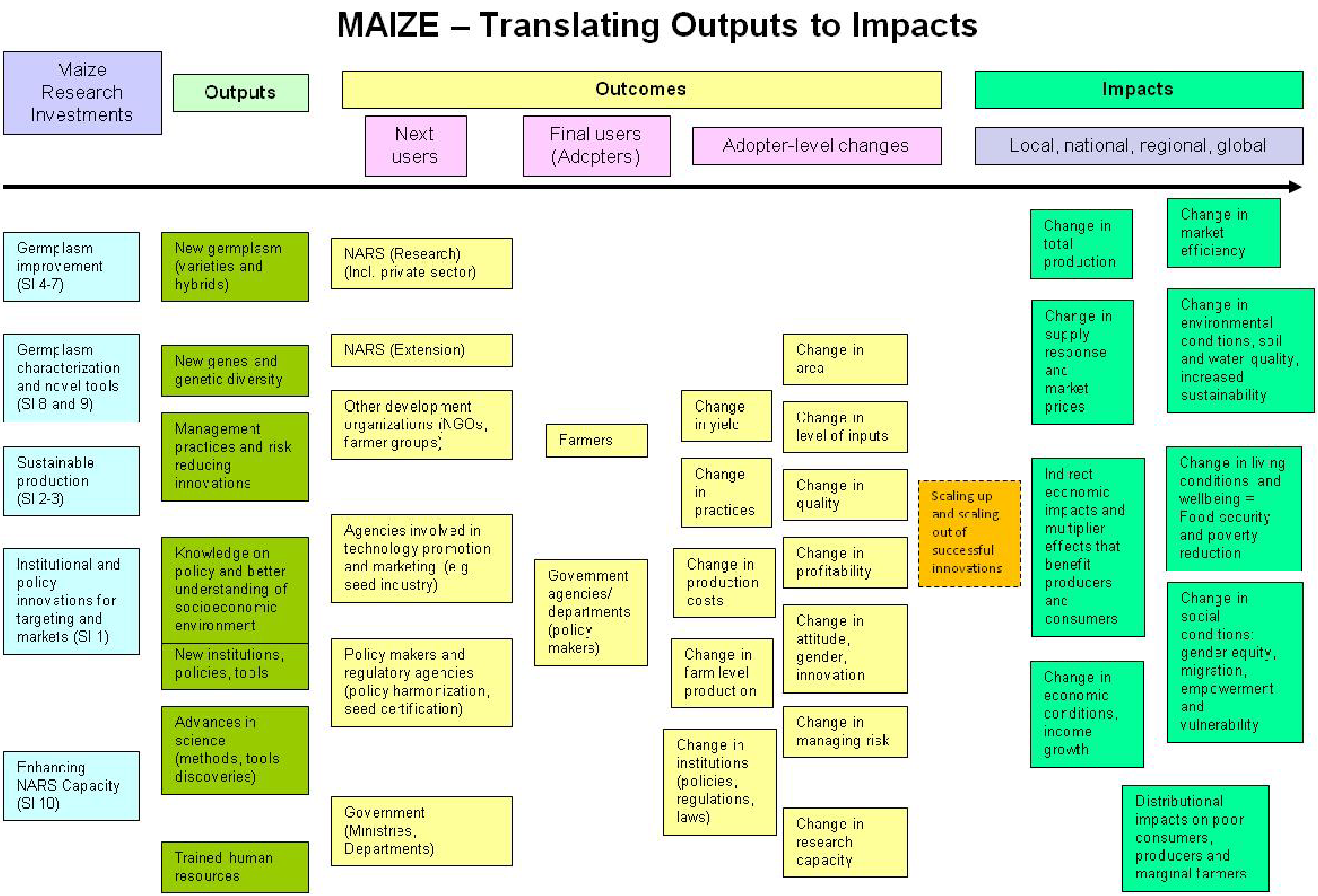
Annex 3. Impact pathways for MAIZE: factors involved in translating outputs into outcomes and impacts[16]

Main outputs of MAIZE SIs	Outcomes as factors that determine 1st order impact (how, by whom and assumptions)	First order impact (Adopter level changes)	Factors that determine 2nd order impact (how, by whom and assumptions)	Second order impact
1. New germplasm: - High yielding variety - Nutritious and healthy grain	• NARS partners adapt the new HY varieties to local conditions. • NARSs and NGOs integrate information and make it available to farmers. • Seed companies and farmer organizations produce seed. • Private sector provides fertilizer and other inputs. • Farmers plant new HY varieties.	• Increased yields. • Area expansion. • Increase in maize production by farmers. • Reduction in the cost of production. • Increase in marketable surplus. • Increased profitability. .	• Increased participation of seed companies for production and wider diffusion of high yielding varieties. • Improved market opportunity for farmers. • Information flow and knowledge creation through extension. • Scaling out/up of new HY varieties across impact target domains through public and private sector partners.	• Increased **food security** for smallholder farmers. • Improved **nutritional security** for women and children. • Increase in supply and **reduced food prices** that increase real incomes of the poor and make food more affordable to net-buyers. • Increase in production that contributes to **local employment and income**. • Increased **farm household income**. • **Reduced poverty.**

- **Outputs** – first and most immediate results of maize research that will contribute to influence change by actors and final adopters.
- **Outcome** – external use adoption or influence of the maize research outputs by the next and final users that results in adopter level changes which are required to achieve the intended impact (NARS research, NARS extension, government, NGOs, farmers).
- **Impact –** Big picture changes in economic, environmental and social conditions at household, national, and regional levels attributable to maize research.

Main outputs of MAIZE SIs	Outcomes as factors that determine 1st order impact (how, by whom and assumptions)	First order impact (Adopter level changes)	Factors that determine 2nd order impact (how, by whom and assumptions)	Second order impact
2. New germplasm – Disease and pest resistant variety – Drought tolerant – Heat tolerant	• NARS partners adapt the new stress-tolerant varieties to local conditions. • NARS extension and NGOs provide information to farmers. • Seed companies and farmer organizations produce seed. • Private sector provides key inputs. • Men and women farmers plant new risk reducing varieties.	• Higher yields in the face of biotic and abiotic stress. • Area expansion at the farm level. • Increased production. • Reduced vulnerability (risk) from disease and pest attack.	• Increased participation of seed companies for production and wider diffusion of quality seed of improved varieties. • Information flow and knowledge creation through extension. .	• **Reduced vulnerability** to pandemic disease and pest outbreaks. • Increased **food security** in the face of disease and pest attack. • Reduced inter-seasonal maize price fluctuation (resulting from stability of production). • Increased **adaptation to climate change.**
3. Crop and resource management practices and knowledge – Minimum or zero till – Crop rotations – Crop residue retention – Soil and water management – Weed control – IPM	• NARS partners integrating better management into maize cropping systems. • Extension systems unpack relevant information and demonstrate best-bests for adoption. • Extent of expression in target environment. • Other value chain actors package seed, fertilizer and other inputs and make it available to farmers. • Farmers adopt new CA-based practices along with improved varieties.	• Increased yields. • Increased farm level production. • Lower per ha level input use (labor, fossil fuels, fertilizer, pesticides, irrigation water, etc). • Reduced production costs. • Higher profitability of maize production. • Diversification of production. • Diversification of diets and nutrition (crop rotations/intercrops). • Diversification of income sources. • Reduced farm level demand (per area unit) for water. • Improved soil health (SOM, reduced erosion, nutrient depletion). • Change in farmer attitudes and gain in sustainability.	• Farmer participation in local adaptive trials and demos. • Provision of finance to enable investment in new equipment and inputs. • Local delivery of key inputs (fert, CA tools) by the private sector. • Local manufacturing of CA tools by artisans. • Scaling out/up of successful innovations by government and NGOs for wider impact.	• **Improved food security** at farm, national and regional scale. • **Farm level water saving** that may also translate to basin level sustainability of water use. • Greater **system resilience**. • Improved **adaptation to climate change**. • Soil carbon sequestration and reduced emission of green house gases (**mitigation of climate change**). • **Improved air quality** from reduced burning of crop residues.

Main outputs of MAIZE SIs	Outcomes as factors that determine 1st order impact (how, by whom and assumptions)	First order impact (Adopter level changes)	Factors that determine 2nd order impact (how, by whom and assumptions)	Second order impact
4. Institutional and policy innovations – Technology targeting and scaling up tools – Improved value chains and markets – Policies for sustainable intensification in maize systems – Data and tools	• Research teams across SIs adopt and integrate social science findings (gender, supply/demand projections, etc) into research. • NARS partners adapting institutional innovations to local conditions. • Extension and NGOs use targeting and scaling up tools. • Policy makers adopt pro-poor and eco-friendly and climate-responsive policies for sustainable prod growth. • Private sector adopts innovations for improving value chains.	• Increased effectiveness and relevance of research. • Better targeting of constraints and reaching of the poor and women farmers. • Improved delivery of information and inputs to farmers by NARS partners. • Enhanced decision making by policy makers to reduce the impact of climate change. • Better market access for farmers (input and output). • Better farm-gate prices, increased market participation and higher income for farmers. • Income diversification for the poor.	• Increased communication and interaction across teams. • Wider adoption and implementation of recommendations by policy makers. • Complementary investments by private and public sector to improve value chains. • Policy dialogue at nation, regional and global levels for dealing with climate change.	• **Increased food security** for the poor from increased supply response, lower food prices, and low volatility. • **Increased adaptation to climate change** (resulting from adoption of better policies). • **Gender empowerment** and **improved welfare for women farmers**. • **Reduced poverty** in maize-based farming systems
5. Capacity enhancement – Trained human resources – Physical infrastructure for research	• NARSs use new skills and infrastructure to generate and deploy maize innovations. • Extension and NGOs use new tools/skills to improve targeting of women/poor. • Policy analysts actively participate in policy analysis.	• Enhanced capacity for local innovation in maize systems. • Release of new varieties adapted to local conditions. • Better linkages in research and delivery systems to reach the poor and women farmers.	• Leveraging of other training to expand gains. • Openness to new ideas to target women and the poor. • Efficient use of new tools/ equipment by local partners.	• Establishment of **sustainable NARS capacity for R&D** in maize systems. • **Local ability for policy analysis** of future options. • **Better policies** to tackle climate change and ensure food security in maize.



Annex 3—Figure 1. Research interventions, outputs, outcomes and impacts for MAIZE.

Annex 4. CIMMYT maize mega-environments.