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

Proposal submitted by CIMMYT and ICARDA to the CGIAR Consortium Board

In collaboration with

Bioversity, ICRISAT, IFPRI, ILRI, IRRI and IWMI

86 National Agricultural Research Institutes • 13 Regional and International Organizations • 71 Universities and Advanced Research Institutes • 15 Private Sector Organizations • 14 Non-governmental Organizations and Farmers Cooperatives • 20 Host Countries

30 August 2011

CIMMYT[MR]
International Maize and Wheat Improvement Center

ICARDA

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 is incredibly low. 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 ICARDA 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 these submissions. We look forward to discussing them with you in the coming weeks.

Sincerely yours,

Thomas A. Lumpkin

Thomas A. Lumpkin
Director General

International Maize and Wheat Improvement Center
Km. 45, Carretera Mexico-Veracruz,
El Batán, Texcoco,
Edo. de Mexico
C.P. 56130 Mexico
E-mail: t.lumpkin@cgiar.org
Web site: www.cimmyt.org

Tel: +52 (55) 58047501
Fax: +52 (55) 58047558

CIMMYT

Contents

Abbreviations[1]

AFLP	Amplified fragment length polymorphism
CA	Conservation agriculture
CBO	Community based organization
CEO	Chief executive officer
CGIAR	Consultative Group on International Agricultural Research
CGIAR ADE	CGIAR Alliance Deputy Executive
CIMMYT	International Maize and Wheat Improvement Center
CRP	CGIAR Research Program
CWANA	Central and West Asia and North Africa
DArT	Diversity Arrays Technology
DNA	Deoxyribonucleic acid
E & SE Asia	East and Southeast Asia
FAO	Food and Agriculture Organization of the United Nations
GBS	Genotyping by sequencing
GCP	Generation Challenge Program
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
ILRI	International Livestock Research Institute
IP	Intellectual property
IRRI	International Rice Research Institute
KPI	Key performance indicator
LAC	Latin America and the Caribbean
mmt	Million metric tons
NARES	National agricultural research and extension system
NARS	National Agricultural Research System
NGO	Non-governmental organization
PSM	Propensity score matching
QTL	Quantitative trait loci
R&D	Research and development
S Asia	South Asia
SI	Strategic Initiative
SMS	Short message service
SRF	Strategy and Results Framework
SSR	Simple sequence repeat

[1] Most institutional abbreviations are listed in Annex 2.

Executive Summary

Recurrent food crises—combined with the global financial meltdown, volatile energy prices, natural resource depletion, and climate change—undercut and threaten the livelihoods of millions of poor people. Accounting for a fifth of humanity's food, wheat is second only to rice as a source of calories in the diets of developing country consumers, and it is first as a source of protein. Wheat is an especially critical "staff of life" for the approximately 1.2 billion "wheat dependent" to 2.5 billion "wheat consuming" poor—men, women and children who live on less than USD 2 per day—and approximately 30 million poor wheat producers and their families. Demand for wheat in the developing world is projected to increase 60% by 2050. At the same time, climate-change-induced temperature increases are likely to reduce wheat production in developing countries by 20–30%. As a result, prices will more than double in real terms, eroding the purchasing power of poor consumers and creating conditions for widespread social unrest. This scenario is worsened by stagnating yields, soil degradation, increasing irrigation and fertilizer costs, and virulent new disease and pest strains.

These challenges are the grand purpose for a revised strategy for the CGIAR centers engaged in wheat research. The strategy is designed to ensure that publicly-funded international agricultural research helps most effectively to ***dramatically boost farm-level wheat productivity and stabilize wheat prices, while renewing and fortifying the crop's resistance to globally important diseases and pests, enhancing its adaptation to warmer climates, and reducing its water, fertilizer, labor and fuel requirements.*** The strategy aims to enable, support, and greatly strengthen the efforts of national governments, the private sector, farming communities, and international, regional and local organizations—creating or capitalizing on synergies.

Building on the input, strength, and collaboration of over 200 partners from the public and private sector, WHEAT will be the catalyst and apex of an emergent, highly-distributed, virtual global wheat innovation network. It will couple discovery science in advanced research institutes with national research and extension programs in service of the poor in developing countries. WHEAT will pursue 10 "Strategic Initiatives" that build on each other to prioritize, design, validate and disseminate WHEAT technologies.

SI 1. Technology targeting for greatest impact. Work will increase the effectiveness and impact of wheat research on food security, poverty reduction, gender equity, and the environment, through better targeting of new technologies. This will be reinforced by improved policies, strategic analysis, and institutional innovations that strengthen linkages among stakeholders along the wheat input-output value chain. This initiative will interact with and support all other WHEAT initiatives in priority setting, targeting, impact assessment, and monitoring, and with CRP 2, 4 and 7.

SI 2. Sustainable wheat-based systems. Innovation systems that encompass farmers and multiple institutions will enable 10–15 million farmers to adapt and implement sustainable, productive, and profitable techniques. Total farm productivity and incomes from irrigated and rainfed wheat systems will thereby increase by 15–25%, contributing to climate change mitigation and adaptation while reducing soil erosion and degradation, labor, and fuel use. This SI will interact with SI 1, 3, 4, 5, 8, and 10, and with CRP 1.1, 1.2, 2, 3, 5 and 7.

SI 3. Nutrient- and water-use efficiency. Novel methods and decision guides will allow 15 million smallholders in irrigated areas to produce wheat with less fertilizer and water and help smallholder wheat producers in rainfed areas to increase crop yields and reduce their risk of economic losses and hardship. SI will interact with SI 2, 4, 6, 9, and 10, and with CRP 1.2 and 5.

SI 4. Productive wheat varieties. Robust, farmer-preferred wheat varieties will bring a 1% per annum growth rate in wheat productivity to be maintained solely by breeding, beyond agronomic interventions, and despite climate change effects that would otherwise increasingly reduce wheat production. SI 1, 2, 3, 5, 6, 7, 8, 9 and 10, with close linkages with CRP 1, 4 and 7, and GIBS.

SI 5. Durable resistance and management of diseases and insect pests. Enhanced genetic resistance and management options for diseases, insect pests, and viruses that cause significant economic losses on millions of hectares of wheat lands will safeguard USD 1.0–2.5 billion worth of wheat production, as well as the livelihoods of millions of farmers affected by virulent new disease strains in developing countries. This SI will interact with SI 2, 4, 8, 9, and 10. Linkages with other CRPs will be via SI 4 product delivery.

SI 6. Enhanced heat and drought tolerance. New genetic and physiological technologies will restore wheat productivity in developing world areas vulnerable to climate-change-induced heat and drought stress and escalating food prices, thereby reducing these threats for over 900 million people—one-seventh of the world's population—particularly in South and Central Asia. This SI will interact with SI 3, 4, 9, and 10, with strong interactions with CRP 7.

SI 7. Breaking the yield barrier. Cutting-edge interventions will raise the wheat's genetic yield potential by as much as 50%, tapping into complementary expertise and the innovation capacity of the public and private wheat communities worldwide, thereby ensuring long-term food security for humankind. This SI will interact with SI 4, and 9.

SI 8. More and better seed. More diverse wheat seed systems will offer developing country farmers quicker access to improved varieties, encouraging broader public and private participation, as well as alternative and innovative seed production and marketing by farmer groups and communities. This SI will interact with SI 1, 2, 3, 4, and 5, with CRP 2.

SI 9. Seeds of Discovery. A researcher/breeder-oriented data platform that will foster and support comprehensive use of the native diversity of wheat and its wild relatives, thereby accelerating breeding gains and counteracting climate change effects and water, land, and nutrient scarcities. This SI will interact with SI 1, 3, 4, 5, 6, 7, 10 and MAIZE SI 8, and GIBS.

SI 10. Strengthening capacities. This initiative will train a new generation of wheat professionals, with a strong focus on women and young professionals, enabling national wheat improvement programs, in partnership with CGIAR institutions and other stakeholders, to improve the efficiency, impact, and sustainable intensification of wheat-based cropping systems. This initiative will interact with and support all other WHEAT initiatives and, with MAIZE, capacity development and information management and dissemination.

During recent decades investments in international commodity research have fallen and yield productivity gains have slowed; even more so in wheat, a crop for which there has been little private sector involvement. Inelastic demand, depleted physical stocks, focus on production in a few "breadbaskets," and the overreaction of governments and financial markets have brought the world to a situation where relatively small, weather-related production shortfalls, in a single breadbasket, leads to large price fluctuations, affecting up to 2.5 billion poor consumers and impacting social stability. It is time for decisive action to close the wheat yield gap in low- and middle-income countries. These countries account for two-thirds of the world's wheat production. New technologies and an international alliance of concerted investments are required to meet wheat demand from expanding populations, both rich and poor.

Activities under WHEAT focus on the developing world and have been prioritized with developing country stakeholders, but WHEAT integrates a global wheat community through active participation in initiatives such as the International Wheat Sequencing Consortium, the Borlaug Global Rust Initiative, the International Triticeae Mapping Initiative, the Wheat Yield Consortium, the International Research Initiative for Wheat Improvement, and the Hybrid Consortium, to name a few. As a result, WHEAT partners are uniquely placed to exploit and contribute to international efforts, as well as to apply results for the benefit of developing world agriculture.

In line with specific requests from the global wheat research and development community, leadership from WHEAT will come in exploiting the wild relatives of wheat through new synthetic wheats, in cytogenetic manipulations for alien gene transfer from wild and cultivated relatives, in finding new sources of pest and disease resistance (particularly rust resistance), in new physiological tools for selecting heat and drought tolerant lines, as well as applying systems-based approaches and precision agriculture technology to improve the productivity, sustainability, and resource-use efficiency of the developing world's wheat production systems. Through its linkages with international efforts, WHEAT will benefit from developments in advanced economies in crop genomics, genetics, pathology, physiology, and agronomy; it will direct emerging technologies from that work into varieties and production systems adapted for lower-income wheat growing countries.

With a targeted annual budget rising to USD 93.4 million – to which the CGIAR currently contributes approximately 18% of the funding through unrestricted support, and bilateral CGIAR and non-CGIAR donors contribute approximately 32% of the funding through over 100 individually designed projects, WHEAT technologies and outcomes will lead to 21% increase in productivity in the target domain by 2030, adding an annual value of USD 1.3 billion by 2020 and USD 8.1 billion by 2030. This will reach up to 40 million farm households and provide enough wheat to meet the annual food demand for many wheat consumers—an additional 56 million in 2020 and up to 397 million in 2030.

WHEAT will be implemented in partnership with new and existing partners from:

- CIMMYT, ICARDA, Bioversity, ICRISAT, IFPRI, ILRI, IRRI and IWMI.
- The Genomics and Integrated Breeding Service (GIBS), and the Generation Challenge Program.
- 86 national agricultural research institutes.
- 13 regional and international organizations.
- 71 universities and advanced research institutes.
- 15 private sector organizations.
- 14 non-governmental organizations and farmer cooperatives.
- 20 host countries.

Humanity faces tremendous challenges to food security and also must confront 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 resources used sparingly in order that they may support future generations.

1. A Major Wheat Initiative

"The recent food crisis—combined with the global financial crisis, volatile energy prices, natural resources 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" (CGIAR 2009).

Wheat provides 21% of the food calories and 20% of the protein for more than 4.5 billion people in 94 developing countries (Braun et al. 2010). The "miracle crop" of the 20th Century, improved wheat varieties adopted during the Green Revolution, saved millions of lives in South and West Asia, China, and Latin America. Wheat's dramatic productivity growth—3.6% per annum during 1966–79 (FAOSTAT 2010)—and production increases in developing countries came from the creation and use of high-yielding, semi-dwarf varieties and improved cropping practices, along with favorable policies and institutional supports.

With wheat and rice leading the way, the Green Revolution dramatically reduced poverty and hunger. Since then, productivity growth has slowed steadily in wheat, slipping to 2.8% during 1984–94 and 1.1% during 1995–2005, an outcome mainly of flagging investments in wheat research and development. Threatening food security in the many regions where wheat is the chief staple, this scenario is worsened by farmers' increasing reliance on rainfed wheat cropping, escalating fertilizer costs (nearly one-fifth of the world's nitrogen fertilizer is applied to wheat), virulent new disease and pest strains, and looming climate change impacts. The ever decreasing physical stocks of wheat, compounded by the decisions of millions of financial market participants and uncoordinated import/export responses by governments have resulted in even small production fluctuations resulting in massive price spikes such as seen in 2010/2011 following the production shortfall in Russia in 2010 of less than 2.5% of global production. The time has thus come for a bold, new, global wheat improvement initiative to satisfy the demand from expanding populations, both rich and poor.

WHEAT is part of a concerted effort of the Consultative Group on International Agricultural Research (CGIAR) to implement a new, results-oriented strategy through a series of Consortium Research Programs. The Programs aim to exploit fully the potential of international agricultural research-for-development to enhance global food security and environmental sustainability, thereby benefiting poor farmers and consumers in low- and middle-income countries. WHEAT will to be at the forefront to benefit from developments in advanced economies in crop genomics, genetics, pathology, physiology, and agronomy; it will direct emerging technologies from that work into varieties and production systems adapted for lower-income wheat growing countries.

The world wheat research community has requested leadership from WHEAT partners to exploit useful diversity from wild relatives of wheat through new synthetic wheats, in cytogenetic manipulations for alien gene transfer from wild and cultivated relatives, in finding new sources of pest and disease resistance (particularly rust resistance), and in new physiological tools for selecting heat and drought tolerant lines, as well as applying systems-based approaches and precision agriculture technology to improve the productivity, sustainability, and resource-use efficiency of the developing world's wheat production systems.

As a result, an alliance of partners including CGIAR centers engaged in wheat research (CIMMYT, ICARDA), national research systems, and advanced research institutes—in partnership with farming communities, private companies, policy makers, and diverse development organizations—will ensure that the following **Vision of Success** is met:

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 changing climate, and their dependence on irrigation and fertilizers is reduced.
3. Increased production in developing countries is achieved mainly through higher yields, thus lessening pressure on forests and hill slopes, encouraging diversification, and reducing competition for space with other crops.
4. Poverty and malnutrition are reduced for wheat consumers, especially women and children, by way of profitable and environment-friendly farming approaches.
5. Disadvantaged farmers and countries gain better access to cutting-edge, proprietary technologies through innovative partnerships, in particular with advanced research institutions and the private sector.
6. A new generation of scientists and other professionals guide national agricultural research in the developing world and work in partnership with the CGIAR, the private sector, policy makers and other stakeholders to enhance efficiency and impact.

The combined challenges of globally-stagnating wheat production, rising consumer demand and higher food prices, worsening water scarcities, and expected climate change effects require efforts that dramatically boost farm-level wheat productivity and reduce global supply fluctuations, while renewing and fortifying the crop's resistance to important diseases and pests. These efforts will also need to enhance wheat's adaptation to warmer climates and reduce the water, fertilizer, labor and fuel requirements of wheat production systems. Scientific evidence says this is possible, but the enormity of the challenges calls for an intensified and coordinated effort of both public and private partners in the developing and developed world.

Such an effort is in line with other summons for coordinated international action on global food security threats, such as the Millennium Development Goal initiatives or the L'Aquila Joint Statement by leaders of the world's largest economies in July 2009. The financial investments required are small relative to total global development assistance or the expected global costs of addressing climate change, but potential returns are high. A successful program will make a significant contribution to ensuring food security for 1.2-2.5 billion poor consumers who would otherwise be priced out of their preferred food staple; it will also help make empowered market participants of more than 30 million farmers in low- and middle-income countries.

1.1 Challenges to Global Wheat Production

Demand for wheat in the developing world is projected to increase 60% by 2050 (Rosegrant and Agcaoili 2010). At the same time, climate-change-induced temperature increases are estimated to reduce wheat production in developing countries (where around 66% of all wheat is produced) by 20-30% (Easterling et al. 2007; Lobell et al. 2008; Rosegrant and Agcaoili 2010). Wheat production will also suffer the effects of stagnating or decreasing on-farm productivity, falling irrigation water supplies, declining soil fertility, and threats from emerging diseases and insect pests. In the absence of unprecedented, coordinated measures to raise wheat productivity, wheat consumers will pay more than twice today's prices for their staple food by 2050 (Rosegrant and Agcaoili 2010).

A critical staff of life and the perils of stagnant yield growth

Accounting for a fifth of humanity's food, wheat is second only to rice as a source of calories in the diets of developing country consumers, and it is first as a source of protein (Braun et al. 2010). Wheat is an especially critical staff of life for the approximately 2.5 billion poor who daily live on less than USD 2 in countries where wheat is among the top three food crops (FAOSTAT 2010; Figure 1; Table 1). Approximately half (1.2 billion poor) are considered "wheat-dependent poor" for whom the crop is a main staple whose production involves some 30 million poor farmers and 170 million poor farm family members.[2]

In the world's 20 principal wheat-producing countries, which account for 85% of all wheat, yields rose annually by only 1.1% during 1995–2006 (Dixon et al. 2009).[3] Based on a 1.1% global yield growth rate, wheat production will be only 17% higher by 2025. This falls well short of the 25% increase needed to keep prices at the current level (Rosegrant and Agcaoili 2010).

Over time, small percentage gaps between yield and demand growth have added up to critical and unsustainable grain supply shortfalls. Global wheat consumption exceeded production in 7 of 10 years during 1997–2006 (FAOSTAT 2008). Inelastic demands, decreasing stocks, and reliance on a few global breadbaskets have given rise to financial speculations and uncoordinated import/export decisions of governments, even after relatively small production shortfalls. As a result over the past two years wheat

[2] This expert assessment was based on wheat production and per capita consumption in wheat growing areas (see Table 1).
[3] The exception is China, where growth is still above 3.0% per year.

prices have already surged above the levels predicted for 2025. Price increases impose great hardship on the poor, as the food price surges of 2008 and since November 2010 made abundantly clear. To avoid recurring and increasingly intense food crises, wheat yields will have to increase at close to twice the current annual rate (Rosegrant and Agcaoili 2010) and wheat prices will need to be stabilized through financial mechanisms, greater market transparency, reinvestments in strategic reserves, and spreading the production risk over a greater number of production areas. With rapidly changing price scenarios and crop substitution, such as that driven by increasing biofuel demands in developed countries, farmers in low- and middle-income countries must close the yield gap and optimize resource use to increase supply and reduce the risk of price spikes.

In most years since 1990, the availability of cheap wheat imports from five key wheat-producing countries and subsidies on consumption led to underinvestment in wheat research by the CGIAR and by many developed and developing countries. Without a pipeline of new research outputs, it is especially difficult to respond rapidly to supply shortfalls and related price increases. Humanitarian concerns over poor consumers will not make farmers or grain storage providers in the developed world respond. High prices will, but based on recent years' realities, those prices seem to be above the levels that poor consumers in developing countries can afford. If wheat and other staple crops are to remain affordable for consumers in low- and middle-income countries, concerted efforts are needed to aggressively adapt and deploy emerging technologies to increase local production in suitable areas in these countries. Low commodity prices are not attractive to farmers, so both wheat production efficiency and economic "yield" will need to increase, to balance consumers and farmers' needs.

Emerging obstacles to progress

Achieving the productivity increases described above will require more than a repeat performance of the Green Revolution: conditions have changed significantly since the 1960s. One difference is that the adoption of improved wheat technology, including new varieties and production practices, has not become an integral component of national agriculture economies. This is partly the result of declining investments in agricultural research and development, low or subsidized grain prices, and a lack of private sector presence in the wheat seed industry. It also reflects the increasing scarcity of water and the degradation of soils. In combination, these factors keep farmers from realizing the benefits of new technologies and thus undercut their incentive to adopt them. By 2050, agriculture's share of water use—now at 70–80%—will decline to 60–70%, through competition with urban areas for diminishing water supplies (Eriyagama et al. 2009). Over the next two decades, farmers can also expect sharp increases in the price of fertilizers, driven by rising costs for fossil fuels and depleting concentrated reserves of phosphorus (Cordell et al. 2010). Adequately irrigating and fertilizing wheat crops will become more difficult; at the same time, rising grain prices will add incentive for farmers to seek more effective practices.

More worrisome yet are the implications of climate change for wheat in the developing world. The crop is expected to suffer the greatest production losses of all major staple crops due to rising temperatures—particularly night-time temperatures—in low-latitude countries. In the absence of significant efforts to improve wheat's heat tolerance, average yield losses of 12–16% are expected by 2025 and of 20–30% by 2050 in low- and middle-income countries, and possibly higher for the most severely affected regions, such as South Asia or CWANA (Box 1).

South Asia's Indo-Gangetic Plains region is especially at risk. This breadbasket created by the Green Revolution currently accounts for 15% of global wheat production and is inhabited by 900 million people, or one-seventh of the world population. It is now considered optimal for wheat farming but, even with carbon fertilization, between 26 and 51% of this breadbasket may be transformed by 2020/2050 from being a most favorable, high-yielding wheat production zone to a heat-stressed, short-season production zone (Ortiz et al. 2008). Considering the compounding impact of receding groundwater tables and increasing irrigation costs, this could result in the politically risky prospect of South Asia having to import as much as one-quarter to one-third of its wheat by 2050. Together, West Asia and North Africa have the highest per capita wheat consumption; their imports as well as yield losses and year-to-year production swings will increase due to rising temperatures, more severe weather extremes, and decreasing water availability.

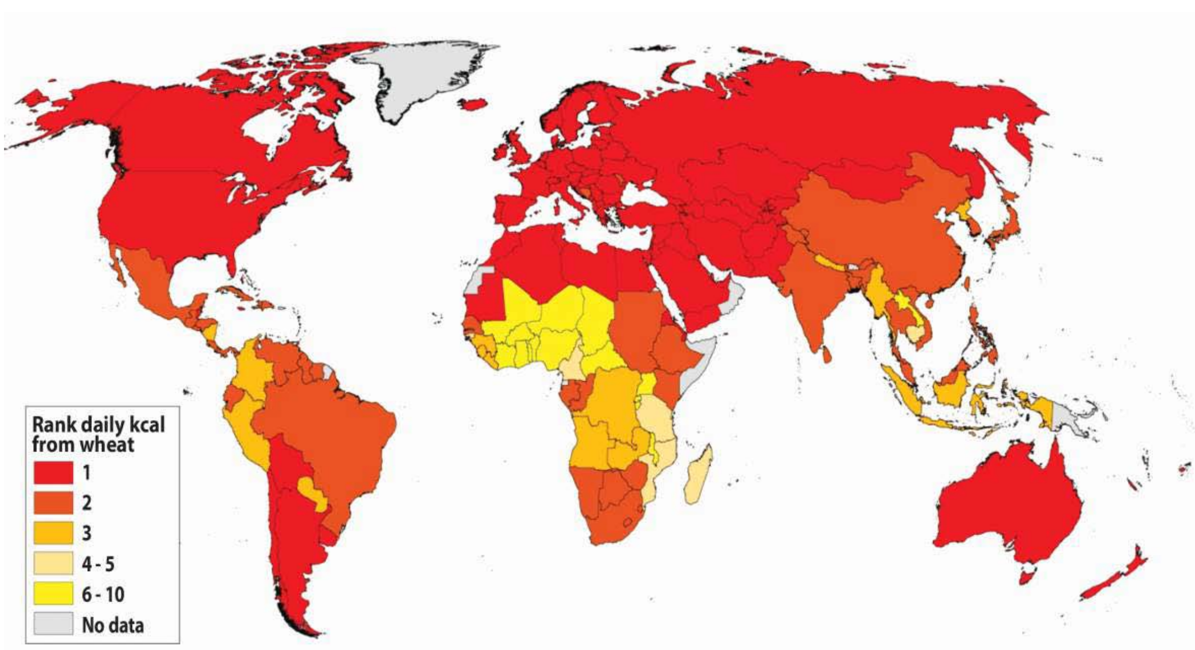


Figure 1. Relative rank of wheat as a food crop worldwide.

Table 1. Global and regional wheat production and consumption statistics in wheat producing countries (FAOSTAT 2010; referring to data for 2007).

Sub region	Area million ha	Production million tons	Yield kg/ha	Population (mlln)	Population < 1 USD/day (%)	Population < 2 USD/day (%)	Million people < 2 USD/ day	kcal/capita/ day
Eastern Asia	23.9	110.4	4,628	1,406	16	45	634	597
Southern Asia	37.2	98.7	2,656	1,542	32	79	1212	481
Central Asia/Caucasus	16.1	26.4	1,633	78	3	31	24	1279
Middle East/North Africa	26.8	61.6	2,296	514	6	23	120	1154
Eastern Africa	1.7	2.9	1,735	229	26	70	160	192
Southern Africa	0.9	2.3	2,934	156	11	21	33	258
Western Africa	0.1	0.1	1,478	184	69	90	165	135
South America	8.4	20.7	2,464	385	9	24	92	430
Central America	0.7	3.6	5,065	131	11	29	37	264
North America	30.2	82	2,728	341	0	0	0	603
Eastern Europe	38.7	100	2,587	295	0	0	0	963
North and West Europe	13.2	90.1	6,820	287	0	0	0	701
Southern Europe	5.8	19.6	3,364	154	0	1	1	836
Australia / New Zealand	12.6	15	1,222	26	0	0	0	547
Total	216.2	634	2,933	5,727	18	43	2478	597

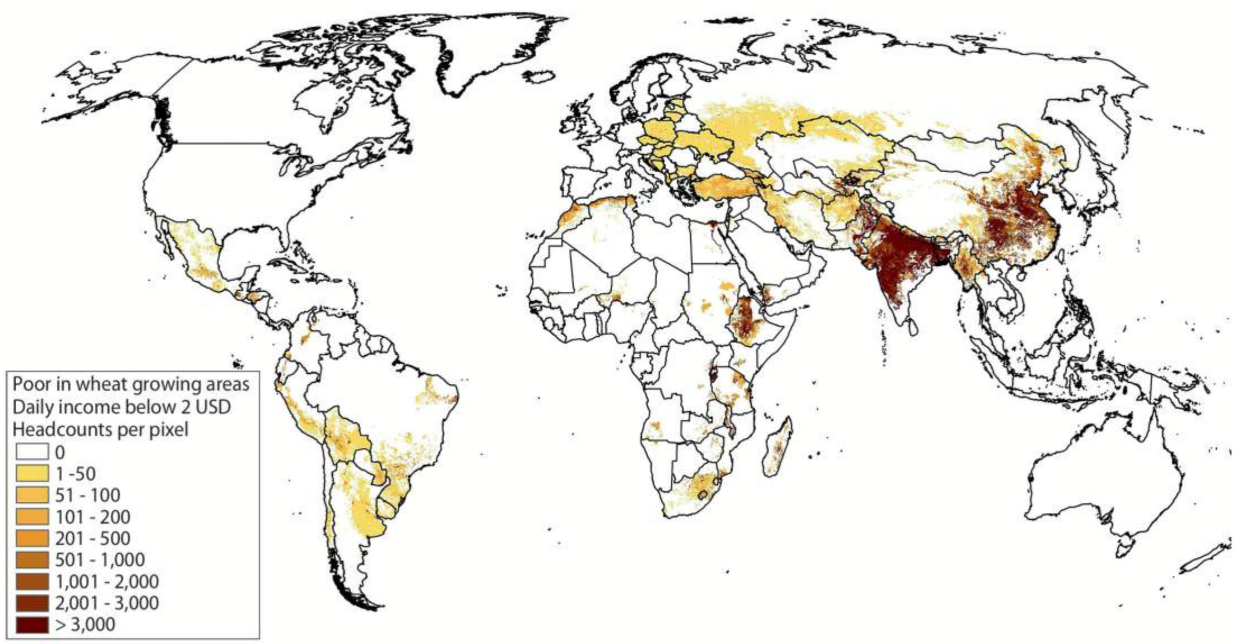


Figure 2. The poor in wheat-growing areas who live on USD 2 or less per day. (1 pixel = 100 km^2).

Box 1. Climate change effects on wheat production

Global climate change (GCC) will have a major impact on crop production, both positive and negative (IPCC 2007). There are many estimates regarding the impact of GCC on crop yield. They are based mainly on climate change and crop growth models and a few laboratory experiments. In several instances they do not refer to the same area or time frame and may or may not include assumed impacts of carbon fertilization or adaptive measures. We summarize here the references most relevant for wheat, which congregate around yield losses between 20 and 30% by 2050 in developing countries with an assumed temperature increase of 2 to 3°C. On a global scale, these yield losses will not be fully compensated by yield gains in high latitude regions (Canada, Russia, Kazakhstan, northern USA), estimated at 10 -15% (OECD-FAO, 2009), since major wheat producers like France report already yield reductions due to increasing temperatures (Charmet 2009).

Heat tolerance in food crops varies greatly. Wheat is among the most sensitive of the major staples, and the impact of GCC on wheat production in the developing world is likely to be severe. Battisti and Naylor (2009) applied 23 global climate models used by the IPCC and concluded that heat will be the main abiotic stress limiting agricultural production. They conclude that without sufficient investments to develop adapted cultivars, the damage seen today in extreme years for temperature will become the norm in the future. Lobell et al. (2008) summarized the results of 6 publications using the CERES-WHEAT model to estimate yield in a global warming scenario and reported yield losses per 1°C temperature increase of between 3 and 17% (average 11%) for northwestern India and Pakistan, between 7 and 12% for northwestern Mexico, and between 9 and 16% for Brazil. These projections convert into 22% losses for South Asia with an expected 2°C increase by 2050 and 33% by 2080 with an expected temperature increase of 3°C (Battisti, pers comm. 2010). You et al. (2009) reported a 3% to 10% yield reduction in China for every 1^{0}C increase in growing season temperature, depending on the region.

Easterling et al. (2007) compiled 67 analyses and estimated average losses for wheat in low-latitude countries without mitigating measures at 24% with a 2-3°C increase and at 40% with a 4-5°C increase. CSIRO and NCAR estimated wheat yield reductions in irrigated areas in developing countries without and with carbon fertilization at 28%/21% (CSIRO) and 34%/28% (NCAR) by 2050 (IPCC 2007). Rosegrant and Agcaoili (2010) estimated wheat production losses across the developing world at 29% by 2050, with higher losses in South Asia. Fischer (2009) considered carbon fertilization and the adaptive measures currently available to farmers and concluded that rainfed wheat production in developing countries in 2050 could fall by 20%/24% with/without carbon fertilization.

Based on these models, it is realistic to assume that wheat yields will decrease 20–30% by 2050 in developing countries, if no mitigating measures are taken, and that negative impacts will likely be greater if the compounding impacts of receding water tables and increasing irrigation costs in regions such as South Asia are considered. The challenge of WHEAT is to develop technologies (varieties, agronomic practices, etc.) that not only compensate for the negative impact of GCC but also allow farmers to produce significantly higher yields than in 2000, with more effective use of irrigation water and nutrients. Even without GCC this is a formidable challenge.

Climate change may also give rise to new or more virulent races of major wheat diseases and pests. The incidence of the Ug99 race of wheat stem rust demonstrates the magnitude of such a threat to world wheat production (www.globalrust.org). More than 90% of the varieties currently in production are susceptible to this race, and production shortfalls could be priced at USD 1 billion or more should a major outbreak occur (Expert Panel on the Stem Rust Outbreak in Eastern Africa 2005).

The potential for wheat breeding to address these challenges could be much better exploited. There are many close wild relatives of the crop that can serve as sources for better tolerance and resistance to abiotic and biotic stress, nutritional and procession quality, and grain and biomass yield potential. Wheat's polyploidy allows easy transfer of genes from these species using conventional approaches. As a C3 crop, wheat also offers great opportunities for breaking its current yield barriers by significantly increasing radiation use efficiency. Finally, of the three major cereal crops, wheat is the most sensitive to high temperatures but also the most water-use efficient. Since heat and drought often go together, this constitutes a strong argument for enhancing heat tolerance and improving wheat’s water use.

There are also unexploited opportunities to optimize the productivity, resource-use, and resilience of wheat production systems in the developing world. Due to stagnating investments in research and extension in the past two decades, million of farmers have been deprived of the types of progress, technologies and know-how available to their counterparts in high income countries. When adapted to their specific socio-economic circumstances, approaches for farming systems optimization, precision agriculture and interactive cell-phone based approaches have much to offer and indeed can rise the productivity in low and middle income countries likely more than in first world bread baskets that are already managed closed to their optimum.

1.2 Impact Targets and a New Strategy for International Wheat Research

The combined challenges of demand growth from the world's rapidly expanding populace, of ongoing poverty and malnutrition, of natural resource depletion, and of climate change will require the concerted engagement of the public and private sectors, policy makers, and many other development partners. Their challenge is *to increase wheat productivity and stabilize wheat prices, reduce its vulnerability to globally important diseases and pests, enable it to grow in warmer climates, and reduce water, fertilizer, labor and fuel requirements for more efficient, sustainable production.* In those ways, WHEAT will seek to mobilize the concerted investment of international, regional, local public, and private sector partners to ensure that the following **impact targets** are met:

1. Raise the annual rate of wheat yield growth globally to 1.6% and lessen the volatility of wheat prices in developing countries, helping to ensure affordable prices for the approximately 1.2 billion wheat-dependent to 2.5 billion wheat-consuming poor.

2. Adapt wheat production in South Asia and other regions that have sizeable areas susceptible to climate change impacts through mitigating measures (agronomy, breeding, policy). This is vital to protect food supplies for about one-seventh of the world's population.
3. Strengthen the sustainability of wheat production despite the continual emergence of damaging rusts and other diseases.
4. Reduce poverty and childhood malnutrition in selected areas where wheat-based farming systems are important; the aim is to benefit 42 million malnourished children with stunted growth.

A new strategy implies changes; focused priorities to deliver impacts specified in the Vision of Success, strong and innovative partnerships oriented toward client needs, coordinated funding and, finally, growth. The current WHEAT strategy was built on formal and informal feedback through the International Wheat Improvement Network (IWIN)—coordinated by CIMMYT and ICARDA and comprising national agricultural research system (NARS) institutions from over 60 developing countries. The Network fosters sharing of germplasm and data and also encourages exploration of evolving insights while promoting focused human resource development, workshops, and staff exchanges. The "nuts and bolts" of this international collaborative system have evolved over time in response to experimentation and learning, changing problems, and resource availability (Byerlee and Dubin 2009). Other components of the strategy draw on more specific consultations and planning of the global wheat community in several priority areas, including:

- The Borlaug Global Rust Initiative (led by Cornell University, 2006–09).
- The Cereal Systems Initiative for South Asia (led by IRRI, 2008).
- The Wheat Yield Consortium (led by CIMMYT, 2009).
- The Hybrid Wheat Consortium (led by BASF, 2010).
- Seeds of Discovery (led by CIMMYT, 2010).

Finally, ever-increasing populations require more food, and politicians are especially aware that hunger breeds social instability. As a result, researchers and policy makers in the developing world's largest wheat-producing countries (China, India, Pakistan, Iran, Turkey and Egypt) specifically instructed CIMMYT and ICARDA to reinvigorate research on yield potential, hybrid wheat, resource-conserving technologies, conservation agriculture, water-use efficiency, and heat tolerance. Much of this research is to address South Asia, where the combined threat of climate change, decreasing water tables, and rising consumer demands will affect one-seventh of the world's population—a threat that has led to a joint call by the Government of India and CIMMYT for increased investment in this region through the Borlaug Institute of South Asia. The urgency of compelling interventions was highlighted by the Prime Minister of India in his Independence Day Speech, both in 2009 and 2010.

Substantive investment will be required to realize the strategy and will involve strategic alliances with institutions worldwide that share the vision of success. As such, WHEAT should be understood as a roadmap—rather than a recipe—that will be adjusted during its implementation based on stakeholder feedback, new partnerships, and insights.

1.3 Targeted Beneficiaries

There are over 10 times more poor wheat consumers (1.2 billion are estimated to be wheat dependent, 2.5 billion are estimated to be wheat consuming) than poor wheat farm family members (estimated at 170 million). Low-, middle-, and high-income wheat producing countries account for markedly differing proportions of global wheat production (3% in low-income countries, 42% in lower-middle-income countries, 21% in upper-middle-income countries, 34% in high-income countries; Worldbank, 2010) and differing proportions of poor inhabitants in their populations (20% in low-income wheat producing countries; 75% in lower-middle-income wheat producing countries, 5% in upper-middle-income wheat producing countries, 0% in high-income wheat producing countries; Worldbank, 2010). The location of poor farmers and consumers in low- and middle-income countries is very important for targeting WHEAT. Research and collaboration must seek to foster food security for poor consumers and added income for poor farmers. WHEAT must foster synergies between researchers, productive wheat farmers, and efficient cropping systems to raise yields, lower grain prices, and deliver benefits to large numbers of poor consumers.

In **low-income wheat-growing countries** over 60% of the population lives in extreme poverty, investment in agricultural research is low, and institutional capacity is often limited. Major wheat producers of this group include Bangladesh, Ethiopia, Kenya, the Kyrgyz Republic, Nepal, and Tajikistan. Although these nations currently account for less than 3% of global wheat production, efforts must enhance the capacity of their national research and development organizations to select and adapt appropriate technologies. Work must also promote the growth of local suppliers of key inputs and information.

Lower-middle-income countries provide the largest share of global wheat production and are also inhabited by the largest number of the poor. Farmers in lower-middle and upper-middle income countries account for 63% (equivalent to ca 400 million tons) of global wheat production, with two-thirds of the volume (270 million tons) coming from the lower-middle-income countries (FAOSTAT 2010). Whereas the proportion of the population that is poor in these countries (24% live on less than USD 1 a day; 58% live on less than USD 2 a day) is smaller than in the low-income countries (where 31% live on less than USD 1 a day and 67% live on less than USD 2 a day), **the lower-middle income countries are home to many more poor people by absolute number**, with a total 800 million living on less than USD 1 a day and a total of 2 billion living on less than USD 2 a day (cf Table 1). These farmers and countries hence offer the greatest opportunities for increasing the food security of the poor. Partners in these countries are eager to obtain new technologies and tools and are well prepared to apply them for major advances in yield growth, thus contributing to adequate wheat supplies and stable prices.

Wheat farmers in **high-income countries** account for 34% of global wheat production and 67% of net exports of wheat. They are well served by strong national research institutions and seed companies, with access to technologies from international wheat research. They provide win-win partnerships that enhance access to advanced technologies and they contribute to faster growth in wheat yields, thus helping reduce prices and benefit consumers worldwide. Researchers from upper-middle and high-income countries who participate in WHEAT contribute significantly to the exchange of useful germplasm and access to new technologies, data, and information.

Recent decades of **global wheat trade** have been characterized by reliance on a few breadbaskets. Seventy percent of wheat exports come from only five nations: the USA, Canada, France, Australia, and the Russian Federation. Recent wheat price developments are showing that overreliance on a few first-world breadbaskets and decreasing stocks constitute an unstable foundation for food prices. Weather-related production variation and farmers' profit-seeking production decisions—currently strongly influenced by biofuel demand and rising energy and input prices—cause fluctuations in global production. These in turn fuel financial speculation, uncoordinated import/export decisions by governments, and price hikes that strongly affect poor consumers in developing countries. Increased market transparency may optimize markets but will not address the underlying reasons for global supply instabilities. WHEAT specifically targets the needs of low- and middle-income countries, which together produce more than 67% of the world's wheat. Closing the yield gap and increasing resource efficiency in these countries is essential to stabilize global production and food prices, while generating income opportunities for poor farmers.

Drivers of change remain largely qualitative. In particular, the recent food price crisis demonstrated a reliance on outdated perceptions of comparative advantage and highlighted the role of risk versus average production. To further quantify the interrelationships between local price realities, the impact of climate change, water and fertilizer costs and availability, the push for more rainfed production, the role of biofuel friendly alternative crops, political stability, policy, and the difference between economic attainable and theoretical yield level in various production areas remains a significant and ongoing research endeavor to be addressed in WHEAT SI1, and in collaboration with CRP2. The focus cannot be on comparative advantage alone but must include risk management of global supply and the need for social stability requested by major wheat consuming countries in the developing world.

Over the years, CIMMYT, ICARDA, and partners have assessed approaches to focus wheat research for specific client groups and environments. One very useful approach has been the definition of 12 principal "mega-environments (MEs)" based on biophysical constraints to wheat production. The MEs range in size from 0.7 to 32 million hectares, and 11 of the 12 are important in low- and middle-income countries (Figure 3, Table 2). The ME based approach has enabled prioritization for international agricultural research engagement, collaboration, and technology exchange.

The wheat mega-environment classification shows that close to 85% of all resource-poor wheat farmers and poor consumers live in spring wheat growing areas that encompass 72% of the total wheat area. The remaining resource-poor farmers live in facultative wheat (8%) and winter wheat (7%) areas (Table 2). Favorable, irrigated, dry wheat areas (ME1) and low-rainfall areas (ME4) are the most important, based on wheat area and the number of the poor, followed by high-rainfall, normal soil (ME2) and warm, humid/dry areas (ME5). ME5 area is expected to increase significantly as climate change transforms ME1- and ME4-type areas. Because of this, WHEAT will focus principally on the four spring wheat mega-environments ME1, ME2, ME4, and ME5, which combined account for 67% of the total wheat area and 900 million (84%) of wheat-dependent poor. Improvements in intermediate-priority areas, which account for 15% of the wheat-dependent poor, will be pursued mostly through collaboration with strong partners such as Turkey and China. The needs of low-priority areas, which account for less than 1% of the wheat-dependent poor, are expected to be met primarily by research efforts from strong alternative suppliers.

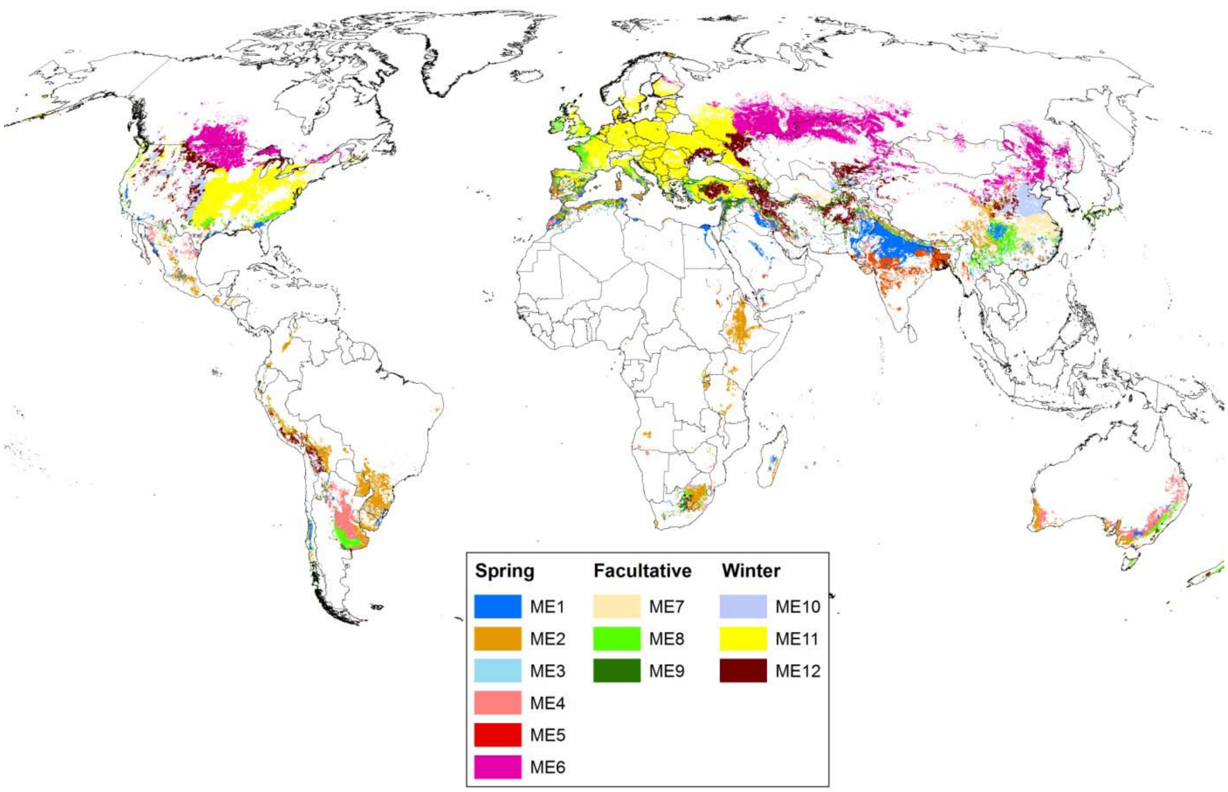


Figure 3. Wheat mega-environments as further described in Table 2. The map only shows the most dominant mega-environment (ME) in each region as choice of production practices (e.g. irrigated or rainfed) and season may affect the type of mega-environment in which wheat is grown.

Table 2. Characterization of wheat mega-environments (modified from Braun et al. 2010).

Major biotic and abiotic stresses: BYD = Barley Yellow Dwarf; CB = Common Bunt; FHB = Fusarium Head Blight; KB = Karnal Bunt; LR = leaf or brown rust; LS = loose smut = *Ustilago tritci;* Nem = Cereal cyst nematodes; PM = Powdery mildew; RDC = Root Disease Complex; SR = Stem or black rust; YR = Yellow or stripe rust.

ME	Description	Wheat area (million ha)	People earning less than USD 2/d (millions)	Priority in WHEAT	Major biotic and abiotic stresses	Representative regions	Change in ME due to climate change and consequences for germplasm development. N=negative P=positive U=unknown (adapted from Hodson and White 2008).
Spring wheat							
1	Favorable, irrigated, low rainfall production	32.0	556	High	SR, LR, YR, KB, Alternaria	Afghanistan, Egypt, India, Iran, Mexico, Pakistan	N–Rising temperatures result in large areas evolving to ME5. N–Reduced precipitation in subtropical regions restricts irrigation. P–Reduced irrigation due to impact of elevated CO^2 on water use efficiency. N–Increased insect problems.
2	High rainfall, low edaphic constraints	7.0	107	High	SR, LR, YR, KB, Septoria spp., PM, RDC, BYDV	Andes, Ethiopia, Kenya, Mediterranean & Caspian coasts, Mexico	U–Changes in precipitation patterns in areas will have variable effects. N–Frequency of climate extremes increase requiring germplasm with high yield potential, wide spectrum of disease resistance and tolerance to variable inputs.
3	High rainfall, acid soil	1.7	16	Low	As for ME2 + acid soil tolerance	Brazil	N–Rising temperatures result in large areas evolving to ME5. U–Changes in precipitation patterns in areas will have variable effects.
4	Low rainfall	21.6	75	High	Drought, Septoria spp., YR, LR, SR, RDC, Hessian fly, Sawfly	India, Iran, North Africa, Syria, Turkey	N–Rising temperatures exacerbate water deficits, either further reducing yields or making production uneconomical. P–Reduced water deficits through impact of elevated CO^2 on water use efficiency.

Table 2. Cont'd

ME	Description	Wheat area (million ha)	People earning less than USD 2/d (millions)	Priority in WHEAT	Major biotic and abiotic stresses	Representative locations	Change in ME due to climate change and consequences for germplasm development. N=negative P=positive U=unknown.
5	Warm, humid/dry	7.1	238	High	Heat, Helminthosporium spp., Fusarium spp., sprouting; wheat blast	Bangladesh, India, Nepal, Nigeria, Sudan	N–Rising temperatures result in large areas becoming unsuitable for wheat; cropping systems and agronomy practices allowing early sowing of wheat paramount. N–Increasing biotic stress. U–Elevated CO^2 may increase water use efficiency, but the same mechanism implies increased canopy temperature, which likely would exacerbate heat stress.
6	High latitude (>45 °N)	20.0	10	Medium	Drought, SR, LR, tan spot, scab, photoperiod sensitivity	China, Kazakhstan, Siberia	P–Rising temperatures allow wheat porduction in higher latitudes - wheat area expansion likely. P- Longer growing season permits marginal areas to become productive. P–Reduced risk of winter kill allows conversion to more productive winter wheat.
Facultative Wheat							
7	Favorable, irrigated, moderate cold	9.0	89	Medium	Cold, YR, LR, PM, BYDV, KB, LS	Afghanistan, Central Asia, China, Iran, Turkey	U–Reduced cold stress allows growing fall sown spring wheat, possibly reducing yield potential but shortening growing season offering more options for diversifying cropping systems. P–Reduced irrigation due to impact of elevated CO^2 on water use efficiency.
8	High rainfall, low edaphic constraints, moderate cold	0.7	2	Low	YR, Septoria spp., PM, Fusarium, RDC	Turkey	U–Changes in precipitation patterns in areas will have variable effects. N–Frequency of climate extremes over years increase, requiring germplasm with high yield potential, wide spectrum of disease resistance and tolerance to drought.

Table 2. Cont'd

ME	Description	Wheat area (million ha)	People earning less than USD 2/d (millions)	Priority in WHEAT	Major biotic and abiotic stresses	Representative locations	Change in ME due to climate change and consequences for germplasm development. N=negative P=positive U=unknown.
9	Low rainfall < 400 mm, winter /spring rainfall dominant	6.8	7	Medium	Drought, cold, heat during grainfill, YR, Bunt, LR, SR	West and Central Asia, North Africa	U–Reduced cold stress allows growing spring wheat, possibly reducing yield potential but shortening growing season. U–Changes in precipitation patterns in areas will have variable effects. P–Reduced water deficits through impact of elevated CO^2 on water use efficiency. N–Rising temperatures exacerbate water deficits, either further reducing yields or making production uneconomical.
Winter Wheat							
10	Irrigated,	4.6	66	Medium	Winter kill, YR, LR, PM, BYDV	Central Asia, China, Iran, Turkey	P–Warmer winters reduce severity of winter kill, increasing yields. N–Warmer spring and summer hasten grain-filling. P–Reduced irrigation due to impact of elevated CO^2 on water use efficiency.
11	High rainfall/ irrigated	Ns			Septoria spp., Fusarium spp., YR, LR, PM, RDC, BYDV	Central and Western Europe, USA	P–Warmer winters reduce severity of winter kill.
12	Low rainfall	7.9	14	High	Winter kill, drought, heat during grainfill, YR, bunts, Nematodes, RDC, Zinc deficiency	China, Turkey, West and Central Asia	P–Warmer winters reduce severity of winter kill. P–Reduced water deficits through impact of elevated CO^2 on water use efficiency. N–increased frequency of years with severe drought. N–Increased insect problems.
Totals		118.4	1,180				

2. The New WHEAT Strategy - Overview

The overall challenge facing WHEAT is to *dramatically boost farm-level wheat productivity and stabilize wheat prices, reduce its vulnerability to globally important diseases and pests, enable it to grow in warmer climates, reduce water, fertilizer, labor and fuel requirements for more efficient and sustainable production, while meeting end users' quality and nutritional needs*. This challenge will be addressed through a set of 10 interrelated Strategic Initiatives (SIs) [4] that have been prioritized based on partner feedback, analysis of target areas (Table 2), the geographic and country-specific location of poor wheat farmers and consumers, the focus of public and private wheat research in advanced economies and the comparative advantage and role of international agricultural wheat research viz national entities, the private sector, NGOs and farmer organizations. In many instances these Strategic Initiatives are already well on the way to being addressed through collaborative or consortium-type approaches (Figure 4). Together, they provide a well-focused, interrelated research portfolio of short- to longer-term and lower- to higher-risk interventions.

Overarching and participating in all WHEAT Strategic Initiatives, SI 1 on technology targeting will provide socioeconomic inputs that aim at: further increasing the effectiveness and impact of WHEAT through better targeting, prioritization and delivery strategies. SI 4, on productive wheat varieties, will integrate the outputs of research on disease and insect pest resistance and management (SI 5), abiotic stress tolerance (SI 6) and breaking the yield barrier (SI 7), and will marshal teams of partners to develop, test and identify potential new varieties. Agronomic and cropping systems research in SIs 2 and 3 will offer yield enhancing technologies, and will incorporate the products of SI4 into sustainable cropping systems, which they will validated through participatory research with farmers. Adoption and benefits from WHEAT technologies will be assured and scaled out through SI2's work with farmers and facilitated by enhanced seed systems through the work of SI8. SI 9 and SI7 are the high-risk, high-potential payoff initiatives of WHEAT's portfolio; they will partner with leading scientists worldwide to examine, adapt, develop and apply cutting-edge genomic and phenotypic technologies, new information platforms and the targeted mobilization of novel diversity into parental germplasm. SIs 7 and 9 will provide much more complete access to the genetic diversity of wheat and its wild relatives—thereby forging paths and enhancing the capacity of wheat breeders and researchers worldwide, including those in SIs 4, 5 and 6, to accelerate breeding gains. SI10 will enhance public and private, individual and institutional capacities by working with and in all SIs, thereby multiplying and empowering others to sustain WHEAT's impacts.

The 10 SIs of WHEAT represent an exciting blend of product development, validation, and dissemination. Here follows a short description of each SI; more detailed justifications, objectives, proposed scientific approaches, outputs, outcomes, R&D partners, gender issues, and impact estimates are provided in Chapter 3.

[4] Strategic Initiatives are concerted, inter-institutional R4D approaches that depend on focused technical expertise, benefit from economies of scale, and are organized for targeting, production, and delivery in a mission-oriented manner. For detailed descriptions of each SI, see the section "Strategic Initiatives."

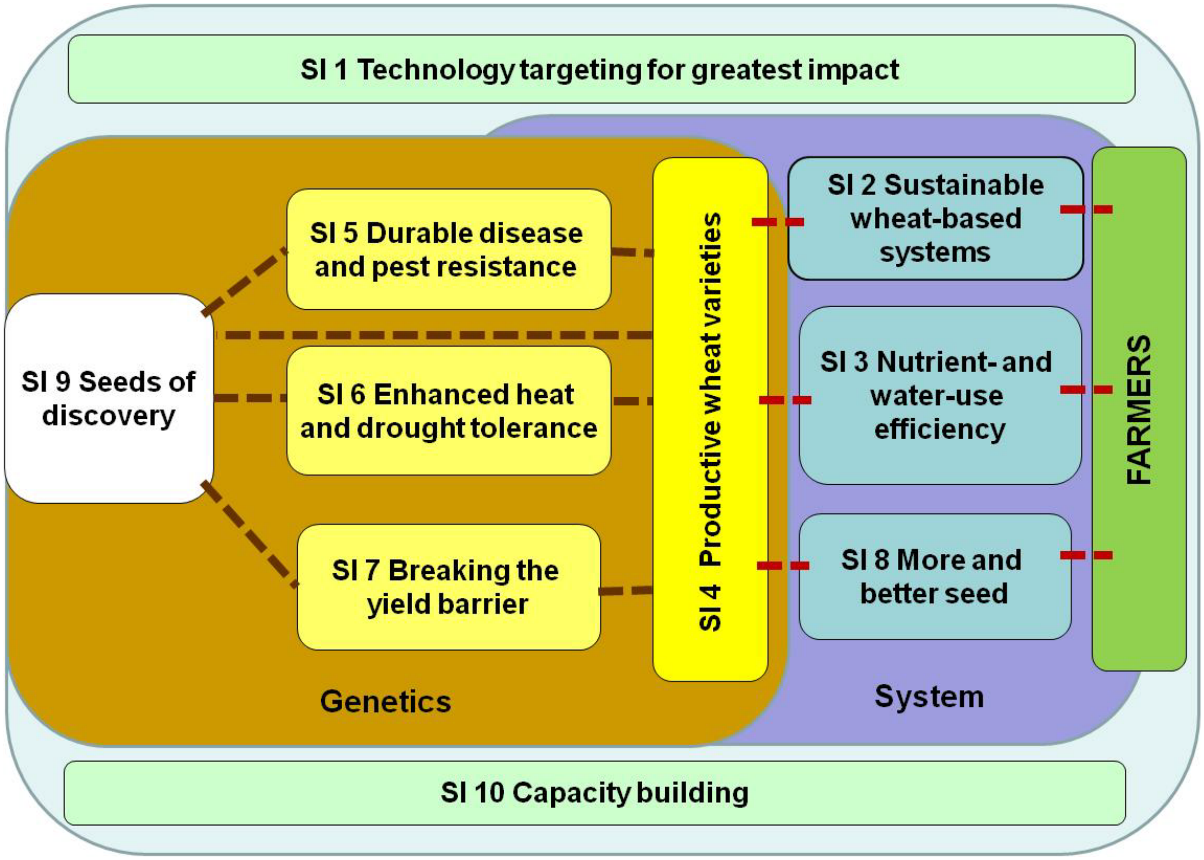


Figure 4. Linkages among WHEAT Strategic Initiatives.

3. The Strategic Initiatives – Genesis, Innovation and Expected Impacts

SI 1: Technology targeting for greatest impact

Genesis: This initiative targets wheat related interventions to generate greatest impact on the poor, women and children and—in collaboration with the CGIAR Research Program CRP 2 'Policies, institutions, and markets for enabling agricultural incomes for the poor'—explore policy interventions that stabilize and establish fair wheat grain prices.

Innovation: Application of novel tools for supply-demand, market and value-chain analysis, to quantify transaction costs, effect of grain quality on prices, market participation patterns, correlations between seed and output markets, gender analysis of wheat interventions, and efficient strategies for linking farmers with markets. New quantitative and qualitative tools and methods for integrated economic, social and environmental impact assessment.

Outputs and expected impacts: Strategic analyses at the global, regional and household level, institutional innovations along the wheat value chain, and policy recommendations that result in positive impacts on wheat price stabilization, income generation, gender equity, greater resource use efficiency, and increased effectiveness of wheat research.

SI 2: Sustainable wheat-based systems

Genesis: Many partners see the implementation of profitable and stable wheat production systems as a priority to increase wheat production while saving irrigation water, fertilizer, land, and energy.

Innovation: Based on successful examples in Latin America and Asia, further create, catalyze and strengthen innovative system approaches through farming system hubs involving researchers, farmers, input supply companies, extension workers and farm implement manufacturers—for accelerated adaptation, testing and scale-out of conservation-agriculture-based systems, varieties, precision farming, and research-to-farmer communication approaches (e.g. cell phone technology) that are adapted to resource-poor farmer conditions.

Outputs and expected impacts: Cross-commodity innovation systems, decision guides, and ICT-based strategies that enable 10–15 million farmers to adapt and implement technologies supporting sustainable farming systems, and thus increase the total farm productivity of irrigated and rainfed wheat systems by 15–25%. SI2 will contribute to climate change mitigation and adaptation and will reduce soil erosion and degradation, while decreasing the needs for labor and fuel inputs to wheat cropping systems.

SI 3: Nutrient- and water-use efficiency

Genesis: Using irrigation, rainfall and fertilizer more efficiently on crop and wheat production is a significant concern to farmers and governments worldwide. Due to underinvestment in agronomy research, fertilizer-use efficiency on wheat varies widely, and farmers get little guidance on how to use inputs more effectively (Heffer 2009; Roberts 2008). While NUE in W-Europe is 44 kg wheat grain for each kg N applied, in China and India it is 22 kg wheat grain per kg N and in Pakistan 18 kg wheat per kg N (IFA 2008, FAO-STAT, 2007).

Innovation: Adaptation of precision agriculture technologies to smallholder farmers conditions; e.g. sensor technology for nitrogen fertilizer dosing (NVDI) now making impacts in precision agriculture in the North will be modified and adapted to the needs of small-scale farmers in the South. Affordable and user-friendly sensors will be validated, allowing optimum nitrogen application in various systems and environments. Improved weather forecasting, fertilizer response predictions and crop modeling will be combined to produce real-time decision guides that can be transmitted rapidly and efficiently by SMS messages to thousands of farmers. New wheat cultivars with enhanced NUE

Outputs and expected impacts: Novel methods, decision guides and information combined with new cultivars will create the conditions for 15 million smallholders in irrigated and rainfed areas to produce wheat with less fertilizer and to increase water productivity, and for smallholder wheat producers in rainfed areas to increase crop yields and reduce their risk of economic losses.

SI 4: Productive wheat varieties

Genesis: This Initiative arises directly from the very successful and much-in-demand International Wheat Improvement Network, IWIN, in which virtually all partners participate.

Innovation: Modern tools—including genome-wide selection, high-throughput marker-assisted selection, increasingly targeted introgression of alleles from wild relatives, and advanced statistical analysis of multi-location evaluation data for wheat breeding—will allow for faster integration of desirable traits and improve breeding efficiency, especially for complex traits such as grain yield under drought and heat conditions.

Outputs and expected impacts: Drawing on outputs from the other SIs related to wheat breeding (SIs 5, 6, 7 and 9—see Figure 4 and below), this initiative will generate robust, farmer-preferred wheat varieties with appropriate processing and consumer quality that maintain the 1% per annum growth rate in wheat productivity ascribable to genetic gains, despite climate change effects that would otherwise reduce wheat production. Agronomic interventions from SIs 2 and 3, production enabling policies from SI 1 above and enhanced disease and insect pest resistance from SI 5 provide additional gains of at least 0.6% so as to reach WHEAT targets.

SI 5: Durable resistance and management of diseases and insect pests

Genesis: Concerted investment in generating durable resistance and managing globally important diseases and insect pests is seen by all partners as an essential input to overcoming major current and future threats to stable wheat production, including those from stem rust, yellow rust and wheat blast. The progress against Ug99 stem rust through concerted international efforts is major evidence supporting this approach. From among the many possible disease targets SI 5 will concentrate on those that affect at least 5 million hectares (see Table 5.1 in the detailed description of SI 5). The targeted diseases and pests may change quite rapidly over the years as a consequence of GCC.

Innovation: Global disease and pest monitoring and predictive systems will be developed in order to prioritize research development objectives. Molecular markers will allow faster responses to new disease virulence and emerging biotic threats, the development of more durable resistance through the stacking of favorable genes, and integrated management options.

Outputs and expected impacts: Enhanced genetic resistance and management options for diseases, insect pests and viruses that individually cause significant economic losses on over 5 million hectares each of wheat lands, safeguarding USD 1.0–2.5 billion of wheat production in developing countries.

SI 6: Enhanced heat and drought tolerance

Genesis: Given the great susceptibility of wheat production to climate change, this Initiative is particularly supported by countries that will be most affected, in particular countries in South Asia, CWANA, Mexico and Sub-Saharan Africa.

Innovation: Integrating physiology more closely into wheat-breeding methodologies and the targeted exploration of native and transgenic variation will greatly enhance elite germplasm development for drought- and heat-stressed conditions. Precision phenotyping and use of controlled, simulation environments will allow technologies to be developed in advance of naturally changing climate and agro-ecological production scenarios. Much of this work is expected to be done in collaboration with South Asia scientists through the Borlaug Institute of South Asia, and through established collaboration in CWANA.

Outputs and expected impacts: Novel genetics to restore wheat productivity in developing-world areas vulnerable to climate-change-induced heat and drought stress, thereby reducing the threat to over 900 million people—one seventh of the world's population—affected by climate change impacts on wheat production.

SI 7: Breaking the yield barrier

Genesis: Although underinvestment in wheat research compared to other crops is part of the reason why breeding gains have slowed, many partners around the world consider that a major effort is needed to break what is considered to be a "yield barrier" in wheat. This Initiative has been launched and is supported by an international consortium of public- and private-sector scientists.

Innovation: Wheat radiation-use efficiency will be radically changed by modifying key enzymes (e.g. Rubisco) and biochemical pathways to increase photosynthesis, while complementary interventions will seek to increase ear size and lodging resistance. Hybrid wheat systems based on native and transgenic interventions will be developed collaboratively, leveraging private-sector technologies for the benefit of partners and stakeholders in the South.

Outputs and expected impacts: Cutting-edge genetic interventions will lead to increases in yield of as much as 50%, tapping into complementary expertise worldwide and the innovation capacity of the wheat community encompassing the global, public and private sectors. Hybrid wheat systems will provide an incentive for the private sector in the North and South to invest in wheat research and deployment, which will provide great leverage in accelerating productivity increases on-farm.

SI 8: More and better seed

Genesis: Most partners state that poorly developed seed systems are a barrier to wheat yield increases in farmers' fields even when excellent varieties are available at the research level. There is need for more proactive engagement in ensuring that genetic gains indeed reach farmers.

Innovation: Emphasis will be on promoting greater market orientation in the public seed sector, as well as increasing the role in seed delivery by the private sector and farmer organizations. The SI will work on researching and scaling out knowledge about promoting farmer-based seed production and profitable marketing units, as well as the rationalization and harmonization of policy and regulatory frameworks that foster faster access to seed.

Outputs and expected impacts: Diverse wheat seed systems that offer farmers in developing countries accelerated access to improved varieties, through broader public and private participation as well as alternative and innovative seed production and marketing by farmer groups and communities.

SI 9: Seeds of discovery

Genesis: Powerful genomics and bioinformatics tools allow scientists for the first time in history to comprehensively examine and exploit the genetic resources available in wheat and its wild relatives, and overcome some of the evolutionary bottlenecks and narrow genetic diversity in wheat.

Innovation: The initiative will use cutting-edge technologies and unprecedented international collaboration to unlock genetic and phenotypic diversity. Top end genomic technologies will be applied with state-of-the-art bioinformatics systems to generate client-oriented information and genetic stocks that provide researchers and breeders worldwide with opportunities for more comprehensively utilizing wheat genetic variability.

Outputs and expected impacts: A researcher/breeder-oriented data platform by which wheat scientists globally can more fully utilize the native diversity contained in the genetic resources of wheat and its wild relatives to accelerate breeding gains and counteract existing and emerging constraints to wheat production.

SI 10: Strengthening capacities

Genesis: The demand for more capacity building of wheat professionals is universal among partners, yet has greatly decreased inside and outside the CGIAR. Through WHEAT, call for an increased number of scientists to receive training aligned to Consortium Research Programs.

Innovation: This initiative will use an integrated approach aligned with the research foci of all other WHEAT Strategic Initiatives, emphasize collaboration with national universities and ARIs for formal training, and strengthen the capacity of researchers, professionals, and partner institutions for implementing new approaches in an impact-oriented manner in their local programs.

Outputs and expected impacts: A new generation of wheat professionals enabling wheat improvement programs to improve the efficiency, impact, and sustainable intensification of wheat-based cropping systems. It will also, indirectly, build the capacity of wheat farmers through the efforts of development partners imparting skills needed for wheat production, especially in fine-tuned systems that better use water and nutrients.

Each of these Strategic Initiatives has a distinct research focus as further described in Section 2 of this document (Page 74 -171). Partners' feed-back was crucial in determining the focus even though a much wider list of research areas was requested to be pursued (Annex A). The final decision on WHEAT research areas was based on the importance for the poor in developing countries, the comparative advantage of international agricultural research and the role of alternative suppliers, including national research systems, the private sector, universities and complementary capacities in advanced economies.

4. Institutional Innovations

Building on past successes: The success of wheat improvement within the CGIAR has been remarkable, and today more than 70% of all spring wheat cultivars grown in developing countries are CGIAR-derived, reaching 90% in South Asia, parts of West Asia, and North Africa. For no other major crop is the percentage of improved cultivars in farmers' fields in developing countries higher than for wheat (World Bank 2008). WHEAT's technology development strategies will be used to validate and integrate a wide range of new approaches into a system of well-proven strategies and to increase the efficiency of output development and dispersion.

CIMMYT and ICARDA coordination: WHEAT will build upon 30 years of joint implementation of the CIMMYT/ICARDA wheat breeding program for Central and West Asia and North Africa (CWANA), implementing a single mechanism to ensure technology development and coordination of global dissemination. It will improve the use of both centers' capacities. The enhanced human resource capacities of WHEAT in specific disciplines allow the Program's coordinated efforts effectively to meet the needs of wheat farmers on approximately 100 million hectares worldwide—in comparison, most public and private wheat improvement programs serve less than 5 million hectares.

Strengthening partnerships: Increasingly fragmented, short-term funding has prevented wheat researchers in the CGIAR from tackling fundamental research and development issues. WHEAT unites the efforts of diverse partners to tackle problems identified and prioritized by stakeholder groups from both the developed and developing worlds. Examples include: the Wheat Yield Consortium (included in SI 7); the Hybrid Wheat Consortium (included in SI 7); the Borlaug Global Rust Initiative (included in SI 4 and 5); and the Cereal Systems Initiative for South Asia (CSISA, wheat-relevant components included in SI 2, SI4, SI5, SI6); and SI 9, Seeds of Discovery.

The G20 Ministers of Agriculture recently declared their support for the CGIAR, GFAR, and GCARD and highlighted the need to promote technology transfers, knowledge sharing, and capacity building through North-South, South-South, and triangular cooperation. The declaration[5] announced the launch of an International Research Initiative for Wheat Improvement (IRIWI) to better coordinate national wheat research in G20 countries with CGIAR WHEAT–led efforts directed at the needs of the developing world. It is important to note that IRIWI is a coordinating entity, not a funding body. The declaration similarly endorsed GRiSP.

Ongoing discussions with national wheat scientists in advanced economies, including those that led to the formation of IRIWI, have specifically concluded that leadership from WHEAT should come from: exploiting wheat's wild relatives through new synthetic wheats; discovering cytogenetic manipulations for alien gene transfer from wild and cultivated relatives; finding new sources of pest and disease resistance (particularly rust resistance); leveraging new physiological tools for selecting heat and drought tolerant lines; and applying systems-based approaches and precision agriculture technology to improve the productivity, sustainability, and resource-use efficiency of the developing world's wheat production systems. Through its involvement with IRIWI, WHEAT will strengthen its ability to benefit from developments in advanced economies in crop genomics, genetics, pathology, physiology, and

[5] http://www.g20.utoronto.ca/2011/2011-agriculture-plan-en.pdf

agronomy; it will direct emerging technologies from that work into varieties and production systems adapted for lower-income wheat growing countries.

Public-private partnerships: The private sector has shown increasing interest in wheat, with three multinational corporations opening research programs in North America within the past 12 months. The private sector and WHEAT partners have complementary R&D capabilities and wheat breeding assets, albeit divergent geographic priorities. Models are being developed that speed technology development through clearly-defined, win-win partnerships for wheat improvement. Examples of such partnerships are already operational. International centers offer technologies, resources, and skills to raise agricultural productivity and sustainability for the developing world. The private sector brings cutting-edge technologies that can make research much more efficient and effective. WHEAT is serving as a catalyst and apex of an emergent and highly-distributed, virtual global wheat innovation network—one that increasingly couples discovery science in advanced research institutes and the private sector with public research and extension programs in developing countries.

Reintegration of capacity building with research: Training of scientists is a key component to achieve impacts in farmers' fields. Since the early 1990s, investment in capacity building has greatly decreased inside and outside the CGIAR, resulting in a great lack of trained agricultural researchers (FAO 2005). Training and engagement of young researchers in the methods and approaches used in WHEAT is mandatory for local innovation, adaption, and scale-out of WHEAT outputs (and therefore formulated in SI 10). The lack of such involvement and investment could well impede the impact of WHEAT and other CGIAR Research Programs (CRPs). Donors call for impact and impact pathways, yet have, in the past, curtailed one of the CGIAR's most effective approaches to ensure that international research outputs reach farmers. Through WHEAT, partners call for an increased number of their scientists to receive training aligned to Consortium Research Programs. Given aging research capacities and below-average involvement of women in a large number of target countries, WHEAT will give women and young researchers working in public and SME institutions preferential access to sponsored WHEAT training opportunities.

5. Impact Pathway

The overall goals and impact targets of WHEAT were summarized in Section 1.2. These impacts can only be realized through multiple partnerships and collaborations. Figure 5 illustrates the linkages between WHEAT Strategic Initiatives in relation to other CGIAR Research Programs and national strategies defined by governments and NARSs. They will be further described throughout this document. The Program level impact pathway for WHEAT is depicted in Figure 6, with more details of partner roles in the outcomes of each SI provided in Part 2.

The research-to-impact pathway involves several intermediate steps and, although not depicted in Fig. 7, an intervention can potentially have multiple outputs, outcomes, and impacts (see Annex B). In general, the research interventions in each of the 10 SIs contribute to the generation of appropriate technologies and institutional innovations, as well as capacity enhancement and better policies. These **outputs** are described for each SI in Part 2. Use of the outputs by development partners and progressive farmers will lead to **outcomes**. The outcomes will include: the use and adaptation of research products by NARSs to local conditions; 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 the private sector and agro-dealers to offer wheat farmers seed, fertilizer, and enhanced market access; advancement in knowhow, capacity, and attitudes by local partners in wheat technology generation and in targeting the poor and women farmers. The outcomes of WHEAT will create the conditions for the desired **impacts** to be realized.

The key factors that determine adoption by farmers and diffusion of research products include the appropriateness of technologies, access and awareness to new information by farmers, expected benefits and local availability of new technologies, market access and opportunities (performance of input and output value chains), access to credit, and policies to enable farmer investment in new technologies. WHEAT SIs 1, 2 and 8 will address these issues to improve on past success rates for technology adoption by farmers.

The immediate result of wider adoption by farmers will be greater profitability and more sustainable production. This may also lead to enhanced local capacity to manage production and market risks and changes in farmer perceptions and attitudes. The targeting of women and their access to desired innovations could improve, as could the national capacity for technological and institutional innovation. WHEAT will facilitate these desirable outcomes at the local and national level through closer collaboration with development partners and governments; the latter will in turn play a key role in fostering adoption and impacts.

Impact pathways for each SI will be regularly discussed, updated, and agreed upon with research and development partners and included in revised operational plans for WHEAT. Multiple partner organizations have confirmed their support and desire to participate in WHEAT (see Annex C, D), and are prepared to enter into detailed planning of who will do what once WHEAT is approved and funded.

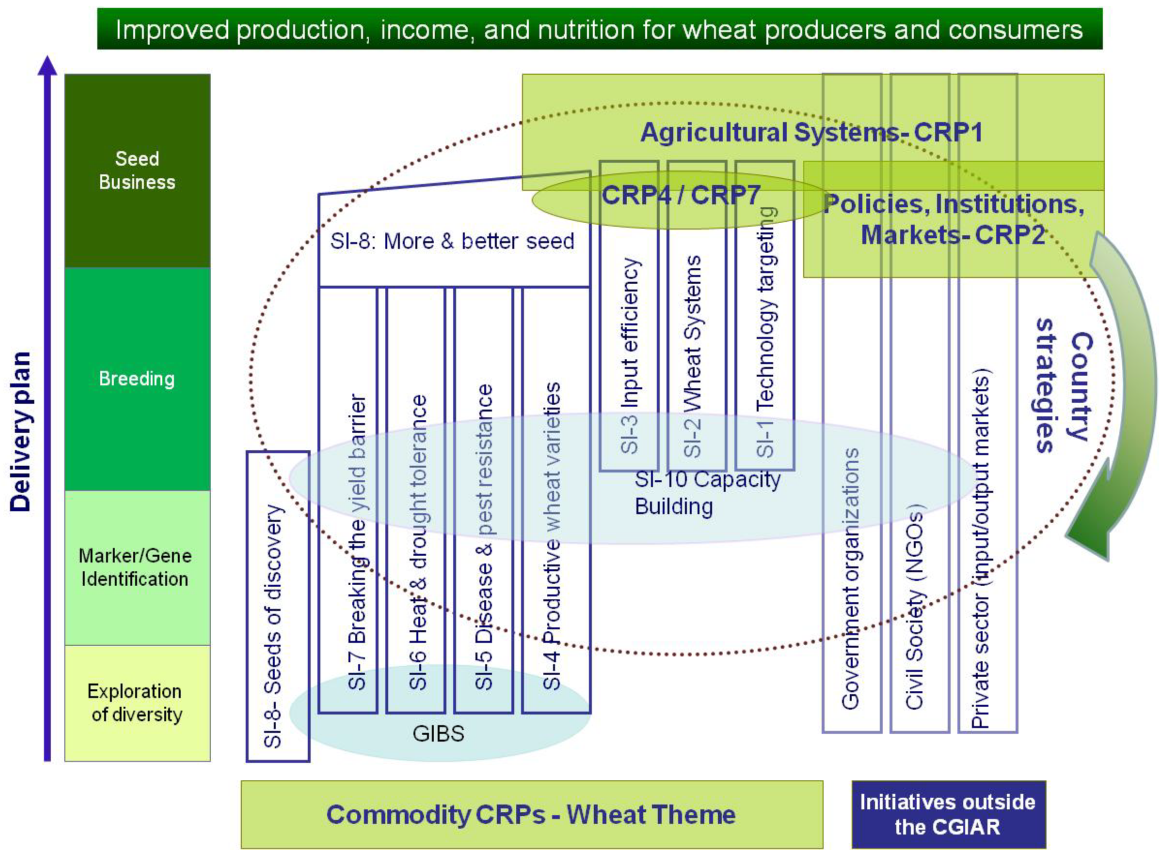


Figure 5. Linkages among WHEAT Strategic Initiatives and in relation to other CGIAR Research Programs and country strategies.

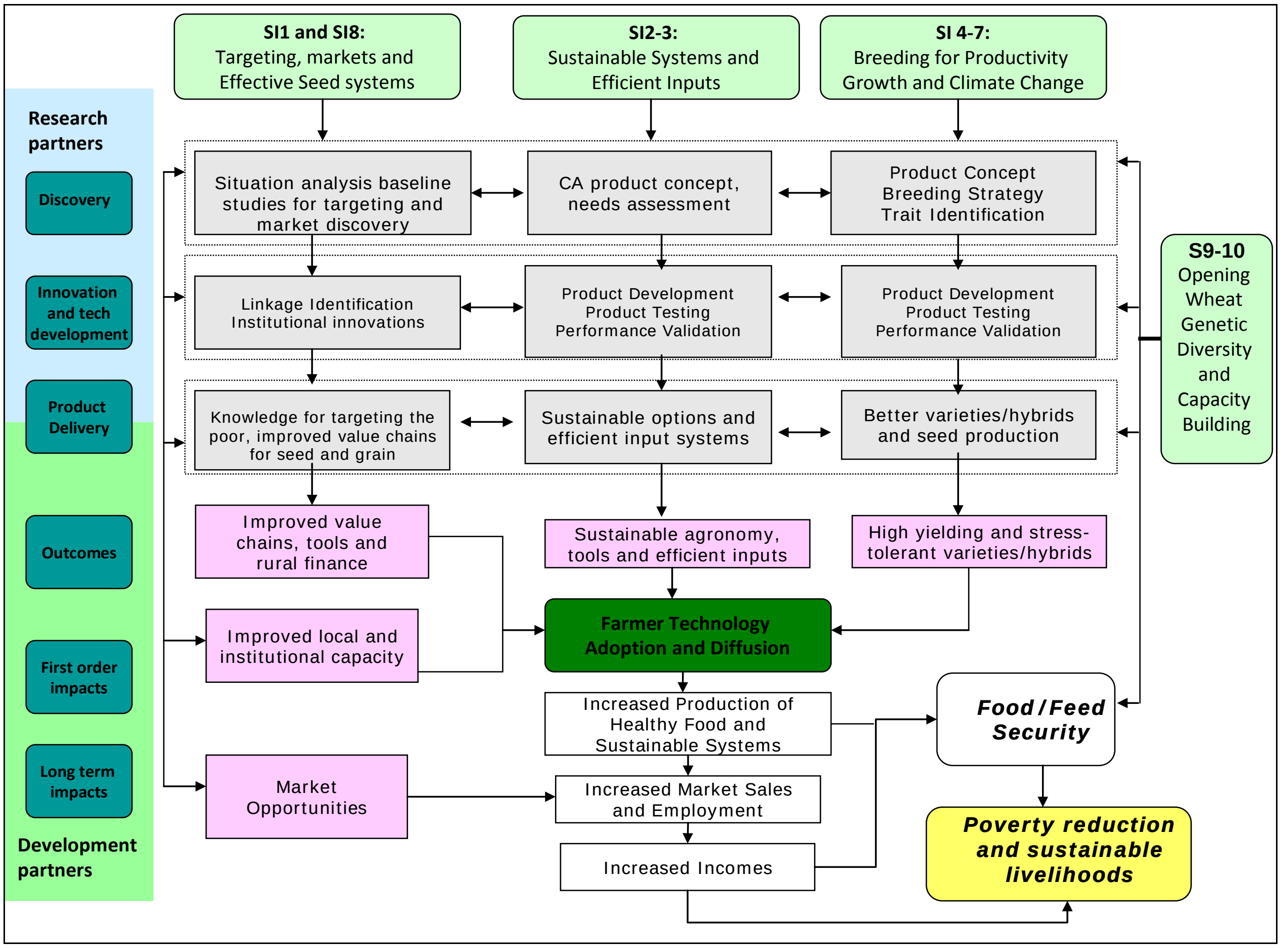


Figure 6: WHEAT impact pathway.

6 Overview of Impacts

Expected impacts of WHEAT on production, people, income, and food realized by 2020 and 2030 are summarized in Table 3 and the linkages to the Strategy and Results Framework (SRF) of the CGIAR outlined in Figure 7. The bases for the impact estimates are outlined in the various SIs. At a fully deployed investment, rising over three years from USD 72.6 million to USD 97.4 million, and not accounting for the ongoing impacts of past research products, WHEAT will further increase productivity in the target domain 21% by 2030, adding an annual value of USD 1.3 billion by 2020 and USD 8.1 billion by 2030. It will reach 25–40 million farm households (assuming some households enjoy multiple benefits) and provide enough wheat to meet the annual food demand for many wheat consumers—an additional 56 million in 2020 and up to 397 million in 2030.

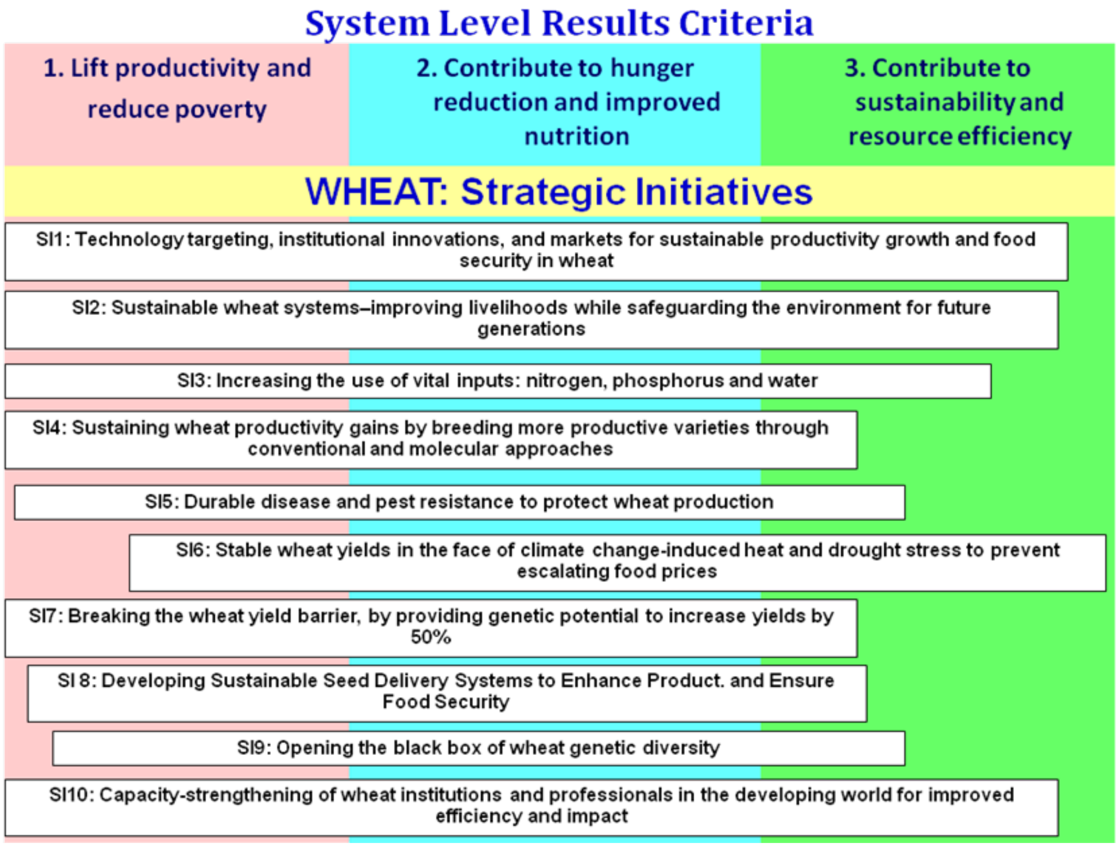


Figure 7. CGIAR system level impacts for WHEAT Strategic Initiatives.

Additional, less quantifiable direct benefits include:

- **Environment:** Increased land, fertilizer and water-use efficiency; improved soil health; reduced soil erosion and flash flooding; reduced water pollution; increased carbon sequestration and reduced fuel use; increased deployment of wheat genetic diversity; reduced need for farmers to expand wheat area into grasslands; and greater crop diversity.
- **Health:** Reduced health risks from misuse of pesticides contamination of water sources and improved nutrition.
- **Equity:** More equitable access to knowledge, technologies, and opportunities for countries, institutions, disadvantaged groups (in particular women) in the developing world; reduced need for imports and food aid; greater dignity for farming as a profession, particularly in marginalized areas; reduced drudgery for women; increased schooling for children; and strong and diverse participation in value chains, and innovation by local agricultural and food processing 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-wheat R&D; stimulation of innovation in national research systems, local entrepreneurs, development partners, and farmers; and science-based information to policy and decision makers.

The estimates in Table 3 show that the main impacts of WHEAT will be macro-level impact on production, more effective use of natural resources, income generation from local production, and the lowering of food prices for poor consumers. The latter is particularly important because when food prices strongly increase the higher prices erode the purchase power of 1.2 billion wheat-dependent to 2.5 billion wheat-consuming poor, with negative impacts on education, health, economic development and a likely rise in political unrest. A shortfall in local production—as is predicted for South Asia, the Middle East and Africa—cannot be solved by trade alone and will lead to higher regional and local wheat prices, even higher than estimates of future global wheat prices.

While one technology alone will rarely take a farm family out of poverty, WHEAT-related technologies can make a substantive impact on the income of a farm household, estimated to averaging USD 200–450 per benefiting farm family (assuming benefits from two to three Initiatives). In instances when drought, heat or diseases wipe out crop production, these technologies can help prevent hunger and the loss of income and assets, and can help prevent farmers from falling back into poverty.

While individual estimates are affected by large variation – as with any other research endeavor – in aggregate they provide an estimate for the aspirations of WHEAT's stakeholders that are quite similar to published past impacts. Improved estimates for each SI will be derived from iterative research feedback, research in SI 1 (Technology targeting for greatest impact), through work with CRP 2 (Policies, institutions and markets), and CRP 7 (Climate change).

Table 3. Summary of impacts of WHEAT on production, people, income and food. Total benefits assume farmers may benefit from multiple initiatives.

Strategic Initiative	Production increase per year (mmt)		Production increase per year (mlln USD)		Farmers (mlln)		Income (USD)		30% of daily calories (mlln people)		Primary impact
	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	
SI 1 Technology targeting for greatest impact	Benefit contained in other SIs										
SI 2 Sustainable wheat-based systems	0.15	2.1	33	504	0.5	7	41.5	603	2	21	Increased production, reduced fuel & labor
SI 3 Nutrient- and water-use efficiency	0.375	1.875	83	450	1.8	10	109	643	4	19	Production increase, reduced fertilizer costs
SI 4 Productive wheat varieties	2.1	2.5	462	600	5	15	462	600	18	108	Production increase, decrease in production and price variation
SI 5 Durable resistance and management of diseases and insect pests	3.2	10.1	704	2,424	5	15	704	2,424	32	101	Production increase
SI 6 Enhanced heat and drought tolerance		5.8		1,392		12.4		1,392		58	Production increase
SI 7 Breaking the yield barrier		9		2,160		15		2,160		90	Production increase
SI 8 More and better seed	Benefit contained in other SIs										Production increase
SI 9 Seeds of discovery	Benefit contained in other SIs										Enabling increased genetic gains
SI 10 Strengthening capacities	Benefit contained in other SIs										Strengthened capacity & institutions
Total impact	**5.8**	**31.4**	**1,282**	**7,530**	**12.3**	**74.4**	**1,317**	**7,822**	**56**	**397**	

"**Production increase per year (mmt)**" was defined by each SI development team, and can be found in the respective SI Value Proposition table.

"**Production increase per year (mlln USD)**" is the product of "**Production increase per year (mmt)**" times the **projected price** of one ton of wheat in 2020 (USD220/t) and 2030 (USD240/t).

"**Farmers (mlln)**" is equivalent to "**Hectares Impacted**", assuming an average farm size of 1 ha.

"**Income (USD)**" was determined as follows:

- For SI 2 and 3, the "**Income (USD)**" = Value increases result from improved input use efficiency and improved grain yield = (Extent of effect [e.g. for SI 2 (10-20%); for SI 3 (25-33%)] * Farmers or Hectares Impacted [assuming an average farm size of 1 ha] * Grain Yield realized [e.g., 1.5 t/ha rainfed; 3.0 t/ha irrigated] * Price of wheat [USD200/mt]) / 1,000,000
- For SI 4, 5, 6 and 7, the "**Income (USD)**" equals a 1:1 projected "Production increase per year (mlln USD".

"**30% of daily calories (mlln people)**" assumes 100 kg of wheat (food) is required per capita to meet 30% of a 2200 kcal diet, and is equal to ("Production increase per year (mmt)" * 1000 kg) / (100 kg / person / year).

7. Gender Strategy

Agriculture is the only realistic driver to reduce mass poverty and promote rural development in most of the developing world (Lipton 2005, World Bank 2008). Furthermore, farming is now recognized as a key pathway out of poverty for women, whose prospects for taking this path improve when they have better access to resources (World Bank et al. 2009). An important element of agricultural development strategies is to enable women to improve food production and engage in higher-value, more economically viable, market-oriented production (World Bank 2008). Women, more often than men, spend their incomes on food, with consequent improvements in household food security, nutritional security, and, especially, the healthy development of children.

The role of men and women in agricultural production and household decision-making varies across the target countries of Africa, Asia, and Latin America. Agricultural research and development interventions may affect men and women differently unless programs are specifically designed to address gender-specific issues and relations that create these disparities. Gender relationships are embedded into complex social systems that generate status, power, and decision-making—considerations that shape the activities of the individuals within these societies (Balakrishnan and Fairbairn-Dunlop 2005). However, women invariably make important labor contributions in on-farm and household activities, often shouldering heavy workloads and drudgery. Several studies have shown that different members within the same household may have different resources, preference, incomes, and needs, and that these factors often vary along gender lines. Thus, there is a pressing need to consider gender-specific constraints and opportunities for men and women as producers and consumers.

Traditions with land tenure, lack of economically viable farm and non-farm enterprises, and wars that distort male representation in local societies all impinge on gender and its role in agricultural development. A combination of rapid population growth and land fragmentation is increasing the numbers of smallholdings throughout Asia and Africa. Many cannot sustain rural households whose sizes and needs are also increasing rapidly. This situation has led to many more males migrating to urban areas or to neighboring countries looking for work opportunities. In addition, recent agricultural intensification trends seem to have stimulated the emergence of a waged labor force that, due to the absence of male workers through significant rates of migration, is now predominantly female (Abdelali-Martini et al. 2003; Balakrishnan and Fairbairn-Dunlop 2005).

Literature sheds very little insight on the extent to which wheat-specific approaches can either address gender-specific needs or create opportunities and empower women. As a result, steps will be taken in WHEAT to understand these differences and leverage this knowledge to inform technology development and delivery systems. Thus interventions will address gender-specific needs, promote options that create opportunities and empower women, and foster strategies that change prevalent attitudes and mindsets to enable equitable and inclusive growth. During the first two years of implementation, as part of SI 1 and in interaction with partner organizations, WHEAT will analyze the gender division of labor, as well as:

- The resulting decision-making power.
- Access to and control over resources (land, water, capital, labor).
- The role of wheat as a cash versus food crop.
- The roles of women and men in wheat production, processing, and marketing.
- Livelihood activities, constraints, and preferences of men and women (adults, children, elders) in different socio-cultural systems in relation to the WHEAT agenda.

The results will be used to strengthen the development of WHEAT technologies and innovations in SIs 2 to 10 to meet women's needs, reduce gender disparities, and engage women more strongly in collaborative research and capacity building. There will also be increased emphasis on training to help agricultural extension agents (or other rural agents) improve their support for women farmers. Current key performance indicators will be updated regularly to monitor progress on gender issues as part of monitoring and evaluation.

Beyond this initial study, socioeconomics research under SI 1 will systematically assess and identify gender-differentiated technology needs, choices, and constraints to inform the design and targeting of new technologies and test mechanisms that enhance technology targeting, delivery, and equitable access, for greater influence on both men and women. In market-oriented cropping systems, access to production resources is crucial, a situation with potential gender inequalities. Efforts to intensify agriculture have been linked mostly to cash crop production, from which men are more likely to benefit. On the other hand, where surplus staple crop production is sold, local food and seed markets are flourishing. These types of markets are often dominated by women (Smale et al. 2008) and will affect the modalities of implementing SIs 1, 2, and 8.

Farmer participatory research in SIs 2 and 8 will actively promote the participation of women, elders, and young adults in technology development, demand studies, variety selection trials, and demonstrations. Such research will analyze the adaptation and adoption of different technologies and varieties in different social settings to maximize positive impacts and minimize adverse effects on women. This may, for example, include the intended and unintended gender effects of labor-saving conservation agriculture or water-saving interventions, and have implications for men and women with varying access and control rights for land and water resources. Understanding livelihood strategies, the resource constraints encountered by women and men, and the roles of women and men in wheat and wheat seed production will form the basis for expanding livelihood opportunities for women.

Technology development efforts under SIs 3 to 7 will be guided by information from SIs 1, 2, and 8 to ensure beneficial targeting of innovations for women farmers. It will take into account the value of wheat for food security and nutrition, as well as family income, and associated trait preferences (storage and processing quality, cooking quality, taste, aroma and color, or nutritional factors associated with alternative varieties). Impact analysis in SI 1 will provide insights on the benefits to children, young women, and other family members of wheat varieties that improve productivity or reduce seasonal losses by countering biotic and abiotic risks.

8. Partnership Strategy

The WHEAT partnership network include some 220 participants, based mostly on past collaborative wheat research projects managed by CIMMYT, ICARDA, and other organizations (see Annex D). Other participants, in particular those with the private sector and upstream genomics capacities, are expected to join as WHEAT is being implemented. Aims will include capturing a range of innovative ideas, ensuring high-quality research, and integrating the most able and well-connected development partners.

Once WHEAT is approved by the Fund Council, the Lead Center will negotiate the contributions and inputs of other partners. An overview of sub-contracted partners and their agreed roles will be included in the annual operational plans and annual reports presented by the Lead Center to the Consortium Board. Complete partner contracts will be available to the Consortium Board on request. Of particular importance is the intended expansion of the group of Primary Research Partners (PRPs) beyond the founding members CIMMYT and ICARDA. PRPs will need to be deeply engaged in fundamental and important research areas vital to WHEAT. Especially in the case of PRPs, the Lead Center cannot complete agreements with new PRPs until they have reviewed the confirmed agreements with the Fund and the Consortium Board. Possible participation in WHEAT, including as PRPs, has been discussed with the Grains Research & Development Corporation (GRDC) of Australia, the Biotechnology and Biological Sciences Research Council (BBSRC) of UK and the Indian Council for Agricultural Research (ICAR). All are strong in applying basic science to address practical wheat production needs in developing countries.

Annex D provides a list of current partner organizations and indicates those that currently receive funding from CIMMYT- or ICARDA-managed wheat research projects. They include: 86 National Agricultural Research Institutes (33 currently funded); 13 regional and international organizations; 56 universities (14 currently funded); 15 advanced research institutes (ARIs); 15 private sector organizations (one currently funded); 14 non-government organizations and farmer cooperatives; 20 countries all receiving funding to host WHEAT offices.

These partnerships provide access to technology and expertise, products, knowledge management and training, scaling-up and scaling-out of capabilities, economies of scale, and delivery systems for knowledge-intensive research. Types of partnerships include:

- Bilateral research collaboration and research consortia involving other CG centers, NARSs, ARIs, and the private sector for distinct aspects of technology development, in particular for germplasm and socioeconomic research.

- Strategic hub-based innovation networks for research, information exchange, and technology transfer involving both public and private entities, in particular for systems-type research (SI 2 Sustainable wheat-based systems, SI 3 Nutrient- and water-use efficiency, and SI 8 More and better seed).
- Collaborations with NARSs, NGOs, CBOs and farmer organizations for technology delivery and capacity strengthening, in particular for SI 2 Sustainable wheat-based systems, SI 3 Nutrient- and water-use efficiency, SI 4 Productive wheat varieties, SI 8 More and better seed, and SI 10 Strengthening capacities.

The partnership strategy is designed to increase research effectiveness and impact. WHEAT will systematically define joint interests and formalize alliances with new and existing R&D partners, creating more effective collaboration and joint fundraising within the innovation system and impact pathways while drawing on principles developed from experience in the CGIAR and beyond (Box 2). WHEAT will give preference to high-quality research and development partners and has developed initial guidelines for selecting such partners (Box 3). In many instances partnerships will imply, implicitly or explicitly, preferential and faster access to research products, information, and training. WHEAT will also explore facility-sharing approaches with key NARSs and ARIs in jointly planned collaborative research—an approach that has already proved effective in gaining the needed scientific inputs and collaboration in critical research areas.

The SIs are diverse and in many instances include different partners. For this reason we do not provide here a generalized list of partners and functions but rather a summary of the main partner roles in each SI (Table 4). Some Initiatives, such as SI 9 (Seeds of discovery), are strongly concentrated on research and information-management partners; others, such as SI 2 (Sustainable wheat-based systems) and SI 3 (Nutrient- and water-use efficiency), need a wide range of national and international partners in both research and development. Several initiatives benefit from a strong interaction of public and private institutions, including SI 4 (Productive wheat varieties), SI 7 (Breaking the yield barrier), SI 8 (More and better seed), and to some extent SI 10 (Strengthening capacities). SI 3 (Nutrient- and water-use efficiency) depends on the novel involvement of cell-phone manufacturers and service providers for research and development of community systems to supply information to farmers.

Box 2. Principles for developing productive partnerships in R&D (based on Woolley et al. 2009)

- Involve the right people and organizations.
- Agree to guidelines on how responsibilities are assigned.
- Agree to clear, shared, flexible objectives that reflect stakeholders' diverse interests and needs.
- Agree to conflict resolution processes.
- Share recognition and responsibility for outcomes.
- Allocate time and resources for effective development of partnerships.
- Allow time for development of trust and a common language.
- Give leadership responsibilities to non-CGIAR partners.
- Clarify expectations about time investment in decision-making.
- Make impact pathways explicit.
- Agree to team standards for response time, sharing credit, and time investment in discussion.
- Agree to supervision responsibilities across institutional boundaries.
- Ensure transparent decision-making and communication.
- Use simple, efficient processes.
- Value performance above politics, seniority, or hierarchy.

Box 3. Desirable attributes of partners

Research partner (all of the following)

- Commitment to the values, outputs, outcomes, and impacts of WHEAT.
- 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 core WHEAT 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 a budget from WHEAT).
- Willing to share field and laboratory facilities.

Development partner (the first two and at least one of the other criteria)

- Commitment to the values, outputs, outcomes, and impacts of WHEAT.
- Demonstrated efficiency and probity in the use of funds (if the partner is to receive a budget from WHEAT).
- A proven track record in improving the livelihoods of smallholders in relevant farming systems.
- The 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.

Table 4. Tentative engagement of partners in collaborative implementation of WHEAT Strategic Initiatives.

Strategic Initiative	Main Partners	Partner Roles
1. Technology targeting for greatest impact	NARESs in Africa, Asia and Latin America.	Country-specific socioeconomic, value chain and gender analysis and targeting, and development of institutional innovations.
	CIMMYT and ICARDA.	Cross-country socioeconomic, value chain and gender analysis and targeting; capitalize on interdisciplinary linkages and know-how of technical and social scientists.
	Consortium Research Programs 2, 3, 4 and 7.	Close consultation between WHEAT and other CPRs will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.
	IFPRI and universities (e.g. Cornell, Georgia, Michigan State, Stanford, UMB-Norway, top universities in Africa, Asia and Latin America).	Cross-sectoral, cross-commodity knowledge, tools, methods and experiences for socioeconomic and value chain analysis and targeting; linkages to policy networks.
	Regional and global policy research institutes, networks and commissions, sub-regional organizations and Ministries of Agriculture and Finance.	Linkages to policy implementation; important clients of outputs of SI 1.
	WHEAT collaborators engaged in other SIs; decision makers in WHEAT and the CGIAR.	Important clients of outputs of SI 1.
2. Sustainable wheat-based systems	CIMMYT, ICARDA, IRRI, ILRI, IFPRI; NARS (Afghanistan, Algeria, Bangladesh, China, Ethiopia, India, Iran, Kazakhstan, Kenya, Kyrgyzstan, Mexico, Morocco, Nepal, Pakistan, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan and Uzbekistan); Universities (Cornell, Stanford, Oklahoma State, Washington); other ARIs (CSIRO, CIRAD, EMBRAPA); NGOs and INGOs (CARE International, Caritas, CRS, Concern Universal, Save the Children, World Vision); FAO, ACIAR, the African Conservation Tillage Network (ACT), APSRU, Australia, East Africa Productivity Program—Wheat of ASARECA, Professional Alliance for Conservation Agriculture (PACA)-India, ASOSID-Mexico; Private sector (machinery manufacturers, input supply, credit, seed traders and associations, regulatory agencies, grain dealers); farmers as the principal partners.	Participation in local innovation systems research and development; all have a role in both research and development.
	Consortium Research Programs 1.1, 1.2, 2, 3, 5 and 7.	Close consultation between WHEAT and other CPRs will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.

Table 4. Cont'd.

Strategic Initiative	Main Partners	Partner Roles
3. Nutrient and water use efficiency	CIMMYT, ICARDA, IRRI; NARSs (China, Mexico, South Asia and CWANA).	Collaborative research on nutrient- and water-use efficiency.
	Consortium Research Programs 1.2 and 5.	Close consultation between WHEAT and other CPRs will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.
	Oklahoma State University.	Nitrogen- and phosphorus-use efficiency.
	Stanford University.	Simulation modeling and remote sensing.
	CSIRO.	Water-use efficiency, phosphorus-efficient varieties, crop modeling, biological nitrification inhibition.
	EMBRAPA; Murdoch University-Australia.	Biological nitrogen fixation.
	Cell phone manufacturers and providers.	Development of community information systems.
	NARESs (China, India, Mexico, Pakistan and later Algeria, Afghanistan, Bangladesh, Ethiopia, Egypt, Iran, Kazakhstan, Kyrgyzstan, Morocco, Nepal, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan and Uzbekistan); NGOs, INGOs; industrialized country development agencies; cell phone service providers.	Field-scale development and adoption of new technologies; diagnosis and feedback on needs.
4. Productive wheat varieties	CIMMYT, ICARDA, more than 250 public and private breeding programs worldwide, including NARS, NGOs, INGOs, CBOs, farmer associations.	Capacity strengthening for complex breeding challenges.
	Consortium Research Programs 2, 4, 7 and GIBS.	Close consultation between WHEAT and other CPRs will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.
	In-service training at CIMMYT and ICARDA and regional courses.	Providing high-priority traits for incorporation and deployment in farmer-preferred varieties through International Wheat Improvement Nurseries.
5. Durable resistance and management of diseases and insect pests	CIMMYT, ICARDA, NARSs, ARIs, private sector.	Collaborative research on pathogen diversity, disease epidemiology, disease/insect pest monitoring, genomic studies, screening for disease/insect pest resistance; IPM.
	In-service training at CIMMYT and ICARDA, KARI-Kenya, EIAR-Ethiopia, ICAR-India, Soil Borne Disease courses in SBD affected countries (NARSs in CWANA, China, India).	Capacity building for pathology research to enable local hot spots for key diseases and pests to contribute to the global wheat network.
	ICARDA, NARSs in CWANA.	IPM for control of insect pests such as Sunn pest.

Table 4. Cont'd.

Strategic Initiative	Main Partners	Partner Roles
6. Enhanced heat and drought tolerance	CIMMYT, ICARDA, NARSs (AARI-Afghanistan, BARI-Bangladesh, China, ARC-Egypt, ICAR-India, AREO-Iran, INIA-Morocco, INIA-Tunisia, Nepal, Pakistan, Sudan, TAGEM-Turkey, Kazakhstan, private sector seed companies; CCAFS, GIBS; ARIs (Australia, France, Germany, Italy, Spain, UK, USA), Private sector; NGOs, INGOs.	Evaluation of wheat germplasm for tolerance to heat and/or drought tolerance .
	Consortium Research Program 7.	Close consultation between WHEAT and CPR 7 will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.
	CIMMYT, ICARDA, NARSs in countries/regions most affected by GCC (ICAR-India, PARC-Pakistan, BARI-Bangladesh, NARC-Nepal, ARC-Egypt, AREO-Iran, Sudan.	Capacity building for research on germplasm development adapted to dry / hot environments; Utilization of physiological methods to characterize wheat for stress adaptive traits.
7. Breaking the wheat yield barrier	ARIs from UK, USA, Australia, France, Argentina, Chile and Spain (Rothamsted, John Innes Centre, Limagrain UK, USDA, CSIRO, ACPFG, INRA, UAC Chile, UBA Argentina, Nottingham, Essex, Liverpool, Australian National, Llerida and Barcelona Universities).	Identification of traits for improved photosynthetic performance, improved lodging resistance and other sources of improved yield potential.
	NARSs in Turkey, India, Egypt, Iran and China.	Deployment of improved yield traits in the field.
8. More and better seed	CIMMYT, ICARDA, NARSs.	Germplasm and variety development.
	Consortium Research Program 2.	Close consultation between WHEAT and CPR 2 will ensure that actions are coordinated to maximize synergies and avoid potential redundancy of activities.
	NAESs with other national partners.	Improved wheat varieties and associated technologies.
	National seed regulatory agencies.	Crop varieties, seeds and phyto-sanitary measures.
	Public sector and emerging local, private-sector companies, farmer groups.	Wheat seed production and marketing.
	Regional and national seed trade associations.	Representing the interests of the seed industry.
	FAO, OECD, ISTA, ISF and UPOV; NGOs.	Seed-sector development.
	National agro-industries.	Wheat processing and marketing.

Table 4. Cont'd.

Strategic Initiative	Main Partners	Partner Roles
9. Seeds of discovery	Wheat-phenotyping network participants in NARSs, ARIs, universities, private sector.	Phenotyping of wheat.
	Triticarte PL, Kbioscience, BGI-Shenzhen, CINVESTAV, GIBS, and other organizations.	Sequencing and genotyping.
	PIPRA; USDA-ARS/Cornell University (GrainGenes), NCBI (GenBank), University of California Riverside (HarvEST), Cornell University (Gramene), CAMBIA (Patent Lens).	On-line register of wheat intellectual property.
	Information technology experts at universities, foundations, and in industry; genomics, genetics, and breeding software developers at universities.	Software for wheat gene database.
	Wheat Phenome Atlas project at University of Queensland, other ARIs, private sector.	Data analysis.
	CIMMYT, ICARDA, NARSs; ARI seed banks (USDA, NIAB, IPK and AWCC); Global Crop Diversity Trust.	Germplasm conservation and pre-breeding.
	CIMMYT, ICARDA, NARSs, ARIs, universities, seed companies, Hybrid Wheat Consortium; private-sector consortia.	Mobilizing novel diversity into breeding programs via seed or introgression lines.
	Patent offices using the WHEAT Diversity Portal.	Evaluating prior art during the patenting process
	Plant scientists worldwide using the WHEAT Diversity Portal.	Production of introgression lines for research.
10. Strengthening capacities	FAO (through the Global Partnership initiative for Plant Breeding), NARESs, IARCs (Bioversity, IRRI).	Geographic and thematic priority setting and needs assessment.
	CIMMYT, ICARDA, ARIs, public and private molecular laboratories, public and private seed companies, IARCs (Bioversity, IRRI), leading NARESs and universities (Brazil, China, India, Mexico).	Resource persons for courses.
	ARIs, Public and private seed companies, Public and private molecular laboratories, IARCs (Bioversity, IRRI), leading NARESs and universities (Brazil, China, India, Mexico).	Development of learning materials.
	Public and private molecular laboratories, IARCs (CIMMYT, ICARDA, Bioversity, IRRI).	Provision of training venues.
	NGOs, INGOs, CBOs, seed trade associations.	Development and dissemination of extension materials.
	NARSs; FAO, ARIs, private sector; trade associations; NGOs, INGOs and CBOs, variety release and certification agencies.	Development-oriented scaling-up of capacity building outputs.
	Top universities in Africa, Asia and Latin America.	Co-supervision of PhD students for "sandwich programs"

The partnerships in different SIs shown in Table 4 can be summarized as follows.

- **National agricultural research systems (NARSs):** Partnerships to pursue specific research and development activities identified as important national priorities have been identified in each SI. WHEAT will identify suitable national partners and fund them through a performance contract for effective implementation of the research agenda that goes beyond national interest. WHEAT will also enter with other international partners into agreements that include co-funding and provision of facilities and human resources based on work plans with clearly defined roles, milestones, and deliverables.
- **International development agencies, regional/sub-regional organizations, and non-governmental organizations:** WHEAT will identify mutually agreeable priorities and mechanisms to implement research and development (R&D) agendas with (1) regional/sub-regional research coordinating bodies, and (2) regional and international organizations and authorities, NGOs and international development agencies such as the Food and Agriculture Organization of the United Nations (FAO) or the World Food Program. Partnerships with NARSs may also be facilitated through the regional/sub-regional organizations, to develop structured arrangements in which multidisciplinary and multi-location research can be prioritized, planned, executed, and evaluated.
- **Advanced research institutes (ARIs):** WHEAT has partnered with ARIs in both the developed and developing world to capture and focus cutting-edge research for product development. There is an additional role envisioned for ARIs in capacity-strengthening and knowledge-management activities; therefore partnerships with ARIs would also include joint development and delivery of training modules, short-term exchange of scientists, and advanced degree research.
- **Other CGIAR Centers:** IFPRI, ILRI, and IRRI currently receive research funding from WHEAT equivalent activities. Several other collaborations are not currently documented as funding flows; funding could evolve for the other centers (ICRISAT, IWMI, Bioversity). For example, in the Cereal Systems Initiative for South Asia (CSISA), as part of SI2, IRRI contributes on rice adaptation to the rice-wheat system and the promotion of rust resistant wheat, IFPRI contributes to the adoption of micronutrient-enriched varieties, and ILRI conducts work on the digestibility of wheat straw and (soon to come) the intensification of wheat-based crop/livestock systems in South Asia. As part of SI3, IRRI will study water and nutrient efficiency and, possibly, applying to wheat the results of future C3-to-C4 conversion in rice. Both IRRI and Bioversity will contribute to needs assessment in capacity building; Bioversity may become a partner in SI9.
- **Public-private partnerships:** Private sector involvement is sought in new proprietary technologies and methods (such as transgenics and molecular markers) relating to wheat improvement, the testing of new materials, and the development, use, or adaptation of new implements (for use in conservation-agriculture-based research) and ICT technologies (data management, scale out of information).

In the past, **partnership interactions** have occurred chiefly through numerous, individually-funded projects. By way of the more systematic approach of SIs, WHEAT will streamline and better focus partnership interactions, using a sequence of actions typical of participatory multi-partner programs (Figure 8). They will include annual collaborative research planning and review meetings specific to one or several SIs, and priority setting across the entire WHEAT agenda to plan revisions of WHEAT. Participatory priority setting using impact pathways, the reality check of available budgets, and peer-review of past and proposed contributions have proven effective tools to choose and agree on partners' activities and roles in within research teams. To involve the greatest number of experts and practitioners relevant to each SI, SI research and planning meetings will be arranged to coincide as much as possible with professional meetings. Thus in 2011, meetings of the International Septoria Conference, the Wheat Yield Consortium, the Borlaug Global Rust Initiative, and the International Triticale Mapping Initiative will be used to sharpen specific SIs and readjust activities based on progress so far. The SI teams will use other opportunities to interact with R&D partners and stakeholders to obtain feedback, innovative ideas and insights. The overall aim is to further develop the WHEAT agenda and better align WHEAT research outputs with development partners' needs.

Figure 8. Collaborative planning and implementation of WHEAT.

9. Linkages and Boundaries with other Consortium Research Programs and Services

The detailed opportunities and needs of WHEAT interactions with other CGIAR Research Programs (CRPs) are shown in Table 5, and alignments along the impact pathway in Figure 5. The delineation described below is based on email exchanges with each CRP facilitator and the Generation Challenge Program (as the facilitator for the Genomics and Integrated Breeding Services, GIBS). Table 5 was developed based on the more detailed descriptions in the various CRPs. During implementation, close consultations among different CRP proponents are intended to ensure coordinated actions. The linkages and boundaries with each of the relevant CRPs will be as follows (for more detail seed Table 5 about outputs from WHEAT to other CRPs, inputs from those CRPs to WHEAT, and joint actions between WHEAT and those CRPs).

CRP 1 Integrated Agricultural Systems for the Poor and Vulnerable, and other Research Programs in CRP 3: WHEAT follows guidelines concerning boundaries of CRP 1, CRP 3, and CRP 5 given at meetings of the Consortium Board with the former CGIAR Alliance Executive in March and April 2010. These principles are also expressed in the SRF. The agreed boundaries and main themes of research for development are illustrated in Figure 9. As programs on major global food crops and drivers for important production systems, GRiSP, MAIZE, and WHEAT were asked to include work on rice, maize, and wheat production systems.[6] As a result, WHEAT focuses on and contributes to progress in poverty hotspots where wheat is a dominant crop in the farming systems and a primary driver of change that increases food security, farm-level productivity, and sustainability. It will include contributions to CRP 1.1 (dry areas, diverse systems with no particular commodity focus), CRP 1.2 (humid tropics, diverse systems with no particular commodity focus), and other CRP 3 Commodity Programs, especially to GRiSP in the rice-wheat farming systems of South Asia. As shown in Table 5, WHEAT will provide genetically enhanced germplasm and innovative component practices, including precision agriculture and efficient N, P, and water use for wheat. CRP 1 and GRiSP will provide feedback to WHEAT on the performance of those wheat components in complex dryland (CRP1) and rice-based (GRiSP) systems and, where necessary, adapt them further for success in those systems, using the FAO farming systems classification as an overall basis for delineation of responsibilities. WHEAT collaborators will work with the other programs where they consider wheat to be an important component in the respective systems.

CRP 2 Policies, institutions, and markets for enabling agricultural incomes for the poor: WHEAT will focus on policy, institutional, and market issues specific to the wheat crop and farming systems where wheat is dominant. CRP 2 will focus on multi-commodity and cross-sectoral issues; it will also support WHEAT with specialized expertise on economic models and policy.

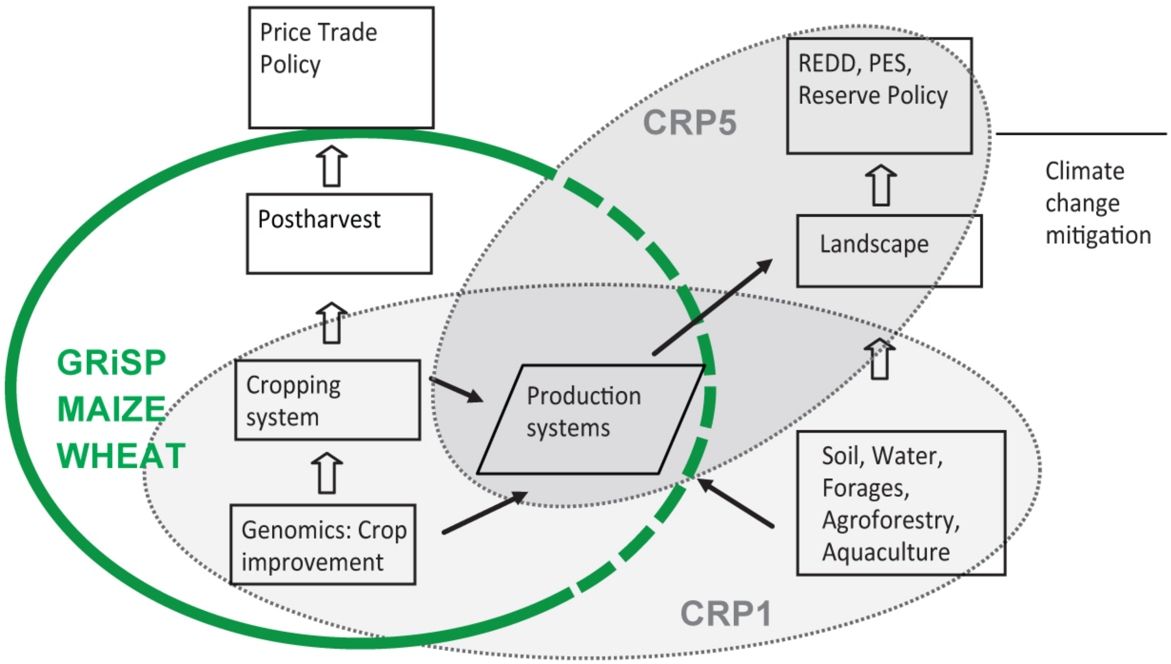
[6] Notes and Decisions, Consortium Board Alliance Meetings, March 27, 31 and 1 April 2010, Montpellier, France.

CRP 4 Agriculture and improved nutrition for health: Based on priority setting and cofounding by CRP 4, WHEAT will focus on generation of nutritionally enhanced wheat and will partner with CRP 4 for technology adoption in target countries. CRP 4 will also focus on technical and institutional aspects of nutrition, including policy, dissemination, and adoption.

CRP 5 Durable solutions for water scarcity and land degradation: The linkages and boundary with this CRP are also shaped and governed by the CB-Alliance-SRF guidelines illustrated schematically in Figure 9 and described in the text above on CRP 1. CRP 5 will provide integrated information, analysis, and knowledge of water, land, and ecosystems at basin, watershed, and landscape scales. It will also provide links to national water and land policies and the global water and environment communities. WHEAT will concentrate on system productivity, resource use, degradation, and regeneration in wheat-based systems. Wheat-based system improvements will need support from CRP 5 to ensure positive or neutral ecosystem impacts. SI 2 will strengthen innovative system approaches through farming system hubs for accelerated adaptation, testing, and scaling of conservation-agriculture-based systems, varieties, precision farming, and research-to-farmer communication approaches (e.g. cell phone technology) which are adapted to resource-poor farmer conditions. Through use of novel methods, decision guides, and information—combined with new cultivars—SI 3 will create the conditions for 15 million smallholders in irrigated and rainfed areas to produce wheat with less fertilizer and less water. Smallholder wheat producers in rainfed areas will be able to increase crop yields and reduce the risk of economic losses.

CRP 7 Climate change, agriculture and food security: WHEAT will develop technologies and information relevant for the success of CRP 7 in climate-change adaptation and mitigation. CRP 7 will provide tools, models and links to the global climate change community. It will also test WHEAT-generated technologies at its pilot sites and provide expert analysis of the context in which they must perform.

Genomics and Integrated Breeding Service of the Generation Challenge Program: The GCP agenda will transition into the "Genomics and Integrated Breeding Service" (GIBS); components associated specifically with wheat (4% of the WHEAT budget) will be integrated into WHEAT, mostly in SIs 4, 6, and 9. The pioneering genomic research and molecular breeding tools for new breeding applications in SI 9 (Seeds of discovery) will become major drivers for GIBS.



REDD= Reducing emissions from deforestation
PES= Payment for environmental services

Figure 9. Agenda and linkages of CRPs 1, 3, and 5 according to the SRF.

Table 5. Interactions of WHEAT with other CGIAR Research Programs.

CGIAR Research Program	Outputs from WHEAT to other CRPs	Inputs from other CRPs to WHEAT	Joint actions between WHEAT and other CRPs
CRP 1.1 & 1.2. Integrated agricultural production systems for dry areas and for the humid tropics. (For CRP 1.1: South Asia, Ethiopia and Eritrea, CWANA, Central Asia and Caucasus countries. For CRP 1.2 rice-wheat systems in eastern Indo-Gangetic Plains)	Genetically enhanced germplasm and innovative practices, including precision agriculture and efficient nitrogen, phosphorus and water use. Insights from value chain (e.g. grain purchasers, millers & backers, input suppliers) are integrated according to their contributions to diversification, intensification, productivity, efficiency, profitability and sustainability.	Feedback on performance of wheat components in complex systems.	Exchange on priority research sites to prevent duplication
		When necessary, final adaptation of practices to specific action sites.	Exchange on priority approaches to foster optimal sharing of insights. Agreement to work in same action sites.
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. Specific gender analysis on wheat innovations. Genetic and agronomic technologies that give high-value opportunities—specialist products and techniques for smallholders and for agro-industry.	Strategic foresight on markets; evaluated institutional innovations for delivery of market information and services to small wheat producers; tested new methods of value chain analysis.	Improved policies, institutions, and market relationships that integrate wheat producers into value chains.
		Policies that encourage breeding for drought tolerance based on demonstrated increases in social welfare.	Cross-country analyses of production and technology policy in wheat-based systems.
		Trend analysis and scenarios for poverty, markets, risk and environment.	Define coherent policies and actions to manage the risks linked to price stability in agriculture. Study impact of price volatility on food security, both for producers, net-food importing countries and other consumers.
	Specific impact assessments and socio-economic analysis on wheat.	Models and tools for impact assessment. GIS information.	Joint research on wheat futures.

Table 5. Cont'd

CGIAR Research Program	Outputs from WHEAT to other CRPs	Inputs from other CRPs to WHEAT	Joint actions between WHEAT and other CRPs
GRiSP in CRP 3. Global rice science partnership	Specific germplasm, practices and information on wheat.	Information on performance of wheat in rice-wheat systems in South Asia and China. Know-how on site specific nutrient management developed for rice, as guide to similar efforts in wheat.	Joint research on rice-wheat systems in South Asia and China, building on the Cereal Systems Initiative for South Asia (CSISA) and the former Rice-Wheat Consortium. Joint strategy for developing and disseminating resource-conserving technologies for cereal systems. Collaboration on comparative physiology research for heat tolerance and raising the yield potential including comparative genomics
Dryland Cereals in CRP3.6. Food security and growth for the world's most vulnerable poor.	Enhanced, more efficient, effective and rapid breeding methodologies developed in SI 4, SI 6 and SI 9.		Exchange of breeding methodology experiences, and genomic information.
CRP 4. Agriculture for improved nutrition and health	Exploration and identification of new traits of nutritional significance. High-throughput, low-cost phenotypic screening for nutritionally important processing-quality traits and associated marker genes; breeding for protein quality & quantity and for micronutrients. Ensuring wheat quality improvements fit with need of processing industry. Specific gender analysis on wheat.	Targeting, advocacy and promotion of bio-fortified wheat. Approaches to reduce the asset gap between men and women, and to empower women to protect the food, nutrition and health of their family. Interventions to increase the consumption of nutrient-rich wheat especially by women, children and other vulnerable groups. Identify points where nutrients are lost and gained in the value chain.	Priority setting for new traits, given value-chain opportunities and needs; co-funding of technology development with the food processing private sectors; and, adoption in specific target countries (particularly for India and Pakistan) for nutritionally improved, biofortified wheat varieties.
CRP 5. Durable solutions for water scarcity and land degradation	Information on water, land and ecosystem changes associated with changes in wheat technology, especially sustainable smallholder systems, precision agriculture, stress-tolerant wheat.	Insights, information and analysis of broader water, land and ecosystem resource management issues; including how drivers of change could influence research. Links to national water and land policy and the global water and environment communities. Information on availability of more efficient irrigation system for wheat.	

Table 5. Cont'd

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

10. Oversight and Management

WHEAT uses a simple, cost-effective design for oversight and management that is based on the management principles defined in both the Strategic Research Framework and the standard performance contract of the CGIAR Consortium (Figure 10). It uses current institutional capacities and networks, and focuses on the pragmatic implementation of a research agenda driven by stakeholder priorities and inter-institutional teams.

WHEAT has initiatives that have global focus (SI7, SI 9), initiatives that have both global and regional focus (SI 1, 3, 4, 5, 6, and 10) and regional focus (SI 2, SI 8). WHEAT will be implemented through a participatory decision making and effective engagement with regional and local partners. The primary focus (see Table 2) will be in East Asia, South Asia, Central and West Asia and North Africa (CWANA), sub-Saharan Africa and Latin America. The implementation will follow the partnership approaches outlined in Parts 6 and 7.

Based on current staff and partner networks, WHEAT will be facilitated in CWANA by ICARDA. CIMMYT and ICARDA have more than three decades of joint research and co-operate at present under the ICARDA-CIMMYT Wheat Improvement Program for CWANA. The TURKEY/CIMMYT/ICARDA International Winter Wheat Improvement Project is hosted by the Ministry of Agriculture of Turkey, and the Soil Borne Disease Program is based in that country. CIMMYT will facilitate WHEAT outside of CWANA. WHEAT is coordinated in all regions in collaboration with established Steering Committees. CIMMYT will also facilitate the implementation of the global Strategic Initiatives SI 7 (Wheat Yield Barrier) and SI 9 (Seeds of Discovery).

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

Definitions of partners

The Program structure depends on various types of partners. WHEAT 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 WHEAT, dedicate significant staff and resources to the objectives of WHEAT, and contribute to the evolution of the WHEAT strategy.

CIMMYT and ICARDA are the founding Primary Research Partners. Additional selected institutions that provide significant international commitment and resources to WHEAT will be included as CGIAR-external Primary Research Partners. Discussions are ongoing with three potential Primary Research Partners: BBSRC-UK, GRDC-Australia, and ICAR-India (see Section 6).

Beyond shaping, investing in, and executing main components of the research agenda, Primary Research Partners will be important champions for WHEAT, contributing to its visibility, accountable for its success, and pursuing and negotiating strategic alliances with research and development partners. Their rights and obligations will mirror those of CGIAR centers. Negotiation of such partnerships is pending, awaiting finalization of performance contracts terms.

Research Partners and **Development Partners** are those awarded performance contracts because of their ability to provide specific, high-quality complementary inputs to WHEAT. Beyond unrestricted funding provided by CGIAR Window 1-3, bilateral projects are negotiated continuously; details regarding those numerous partnerships will appear in annual operational plans and WHEAT reports. Research partners remain autonomous institutions and implement the WHEAT agenda to the greatest extent possible aligned to their institutional approaches for effective management.

Stakeholder Partners participate in priority setting, implementation, and review of research-for-development without contractual arrangements.

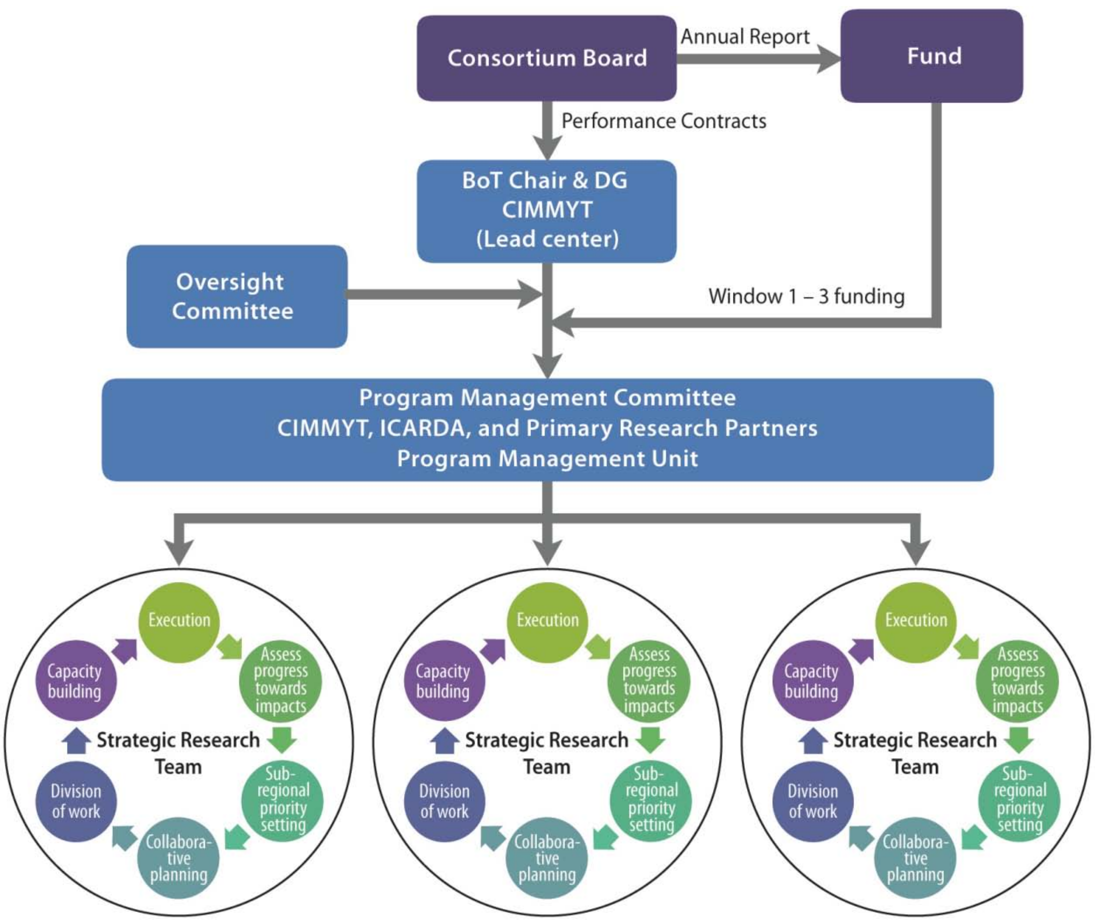


Figure 10. Oversight and management of WHEAT.

Roles and responsibilities

The **Board of Trustees of CIMMYT** has the fiduciary and legal responsibility and accountability for implementing performance contracts with the CGIAR. It will monitor the successful management and implementation of WHEAT, including the effective use of the feedback from the Oversight Committee. Other roles to be taken up by **governance or management entities of all Primary Research Partners** include:

- Ensuring that their institution's or department's policies, vision, mission, and values are in agreement with and facilitate the management and implementation of WHEAT.
- Ensuring appropriate inclusion of WHEAT in their institution or department's Strategic Plan.
- Assuming fiduciary and legal responsibility and accountability for implementing performance contracts.

WHEAT cannot pretend to control governance entities of Primary Research Partners, but the definition of such partners ("Providing significant international commitment and resources to WHEAT") implies their co-ownership of WHEAT, a posture expected to find expression in the institution or department's actions and level of support for / championing of WHEAT.[7]

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

- Support the WHEAT Management Committee and ensure effective collaboration with other program participants in the pursuit of WHEAT activities and objectives.
- Ensure high-quality implementation of research and partnership approaches, including the effective integration of existing bilateral projects and the development of others.
- Assign appropriate staff to the WHEAT Management Committee and implement agreed activities as documented by annual work plans and performance contracts.
- Ensure that systems and policies are in place to successfully manage the performance contracts.
- Manage the risks associated with implementing WHEAT performance contracts.

[7] Such an institutional commitment of Primary Research Partners is different from the implementation of CGIAR Challenge Programs, which mostly contract expertise of individuals from other institutions. The concept of institutional partners has been core to execute large-scale projects such as the Durable Rust Resistance Project implemented by Cornell University in collaboration with more than 30 partners.

In addition, the Director General of CIMMYT will:

- Resolve institutional or personal conflicts among partners that cannot be resolved by the Management Committee, drawing, if necessary, on support and advice from 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 WHEAT by the Consortium Board.
- Represent (or ensure representation of) WHEAT at major global research and development events.

Oversight Committee (OC): This committee oversees WHEAT implementation and comprises individuals who can bring together state-of-the-art scientific expertise and high-level insights from diverse partners. It will have nine members, including representatives from CIMMYT (Chair) and ICARDA, the Chair of the Management Committee, and six regional representatives. There will be one representative for each of the following regions: East Asia, South Asia, CWANA, sub-Saharan Africa, and Latin America, and one member representing collaborators from Australia, Europe, and North America. They will be appointed after receiving nominations from stakeholders within the wheat community (NARSs, private sector, ARIs, farmer organizations, policy makers). Committee membership may be adjusted by the OC itself, if additional Primary Research Partners are appointed.

The Committee will meet annually and interact by email or videoconference as needed. Its role is to:

- Broaden the perspectives and views about WHEAT 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 WHEAT.
- Monitor the overall performance of WHEAT, the relevance of outputs, the feasibility of the 3-year/annual WHEAT workplan and provide such assessments to the Management Committee and the Director General of CIMMYT.
- Advise on opportunities to enhance the performance of WHEAT, strategic alliances with partners, and effective engagement of partners;
- Periodically review the principles that guide CGIAR resource allocations among SIs, regions, partners, and advise to the effective engagement of partners.
- Provide specific advice on partnership strategies, including delivery of outcomes and impacts.
- Advise on gender and capacity building issues.
- Establish principles that assist the Lead Center's DG and the Management Committee in conflict resolution.

The **Management Committee** (MC) is the executive committee of WHEAT. This is an executive working committee consisting of the relevant institutional research directors and program leaders from Primary Research Partners, all of whom oversee implementation of the WHEAT research agenda within their institutions. The Management committee will comprise 10 members or fewer. It will be co-chaired by the CIMMYT and ICARDA Deputy Directors General for Research and Partnerships. Until the formal inclusion of one or several Primary Research Partners (that is, until Primary Research Partners are formally confirmed and performance contracts established), the MC will include external observers from institutions with the highest current research engagement in the global WHEAT agenda, in conformity with the principles included in the SRF. The MC will meet at least twice annually and interact bi-monthly through telephone or video conferencing. The committee is responsible for the global management of WHEAT and in particular will:

- Oversee and be responsible for the quality and relevance of the outputs produced under WHEAT.
- Enhance the overall performance of WHEAT and assist research teams and research partners.
- Plan scientific delivery of WHEAT 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 WHEAT 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.
- Be responsible for timely compilation of WHEAT progress reports against work plans, milestones, outputs, and outcomes from among research partners.
- 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 WHEAT communications strategy and guide the implementation of WHEAT Web- and email-based stakeholder interactions, knowledge management approaches, and the collection of M&E information.
- Oversee and manage the regional and global collaborator teams.
- Coordinate the bilateral fundraising aligned with the WHEAT strategy.
- Oversee contracts between the Lead Center, other Primary Research Partners, and those Research Partners who contribute to WHEAT global activities.
- Seek to fulfill all aspects of the WHEAT performance contract between the Lead Center and the Consortium Board for successful implementation of WHEAT.

A program management unit associated with the Chair of the Management Committee will facilitate the global coordination of WHEAT. The unit will:

- Facilitate the compilation and consolidation of the global WHEAT 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 WHEAT-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 WHEAT, ideally aligned with other CRPs.
- Facilitate collective agreement by the Management Committee, on matters including mechanisms, processes and decision criteria for funding allocations.

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.

Collaborator Teams for various Strategic Initiatives will meet annually and include crucial outside stakeholders, development partners, and external experts who provide insights on the research agenda. They will:

- Review and refine priorities, targets, progress, and impact pathways in view of available resources.
- Agree on research responsibilities of specific partners and the need to involve others.
- Conduct peer review and provide recommendations for 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 WHEAT 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.

Implementation of Strategic Initiatives: Strategic Initiatives are concerted research-for-development (R4D) approaches, based on focused technical expertise, comparative advantage, critical mass, subsidiary and economies of scale. They are organized for targeting, production and delivery in a "mission-oriented" manner to address highest priority concerns of distinct client groups at the global or regional level. Facilitated by the members of the Management Committee, global three-year and annual work plans and budgets will be developed among research partners and revised during annual planning and review meetings. Work plans will define macro-deliverables from respective research partners while exploiting synergies of scale and staff competences, and will become part of the performance contract.

Roles of CIMMYT and ICARDA: Within the WHEAT Strategic Initiatives, CIMMYT will coordinate the global agenda for wheat systems improvement. ICARDA will coordinate the wheat systems improvement agenda for Central and West Asia and North Africa (CWANA), and take disciplinary leadership in entomology (within SI 5) and seed systems (SI 8) research. WHEAT will seek to evolve institutional strengths along the lines of respective institutional mandates, comparative advantage, and donor support.

External advisors: While individual SIs will be guided through the concerted input of research partners, as described in the previous section, meetings of individual SIs may include external advisors that provide high-quality insights on scientific directions, science quality, methodology, and partnership approaches for each Strategic Initiative. Formal advisory boards already exist for SI 7 Breaking the yield barrier and SI 9 Seeds of Discovery. The need for advisors and their qualifications in other SIs is determined by the Management Committee, complementary to qualifications of research partners and while seeking to maximize synergies with the numerous advisory boards and review mechanisms of existing donor-funded projects that fall within a particular Strategic Initiative.

Priority setting to plan future revisions of WHEAT. The initial performance contract with the Consortium Board is for three years (2011–2013) and subsequently will have 6-year horizons. In the penultimate year of a performance contract, stakeholders (sub-regional organizations, NARS leaders and scientists, farmers, representatives from the food processing industry, seed sector, private sector, chemical industry and others) will be consulted electronically to receive feedback beyond that originating from regional and global collaborator teams attending SI-specific review and planning meetings. They will be asked to assess current priorities, provide feedback on lessons learned, and identify potential new priorities for the next performance contract period. Together with results of the impact and targeting work conducted as part of SI 1 and external studies, the compiled feedback will then form the basis for a physical stakeholder meeting in the third year of the Consortium contract, with balanced regional representation. Participants in the stakeholder meeting will formulate the next WHEAT proposal.

Decision-making: WHEAT is committed to transparent cross-institutional team-based approaches and a continuous quest for high-quality science and partnerships. It advocates innovation, pragmatic client- and impact-oriented implementation, minimal bureaucracy and redundancies, and supports capacity building of local partners so they may effectively contribute to, absorb, and benefit from the overall WHEAT agenda. While we apply the principle of subsidiary (that matters ought to be handled by the smallest, lowest, or least centralized, delegated, competent authority), we also acknowledge that synergies exist among SIs, regions, or across WHEAT that sometimes require decision making at a higher level. CIMMYT, ICARDA, and other research partners will ensure that these principles operate in each of their institutions, while the MC will have responsibility at the global level.

Scientific advice: A small group (5–6) of external technical experts – selected from among the external advisors to various SIs – will join annual planning and review meetings of WHEAT and provide a formal report to the MC and Oversight Committee.

Accountability of WHEAT: WHEAT will report progress and achievements to the Consortium, R&D partners, and the general public through annual reports conforming to the SRF. The reports will refer to indicators described in the performance contract with the Consortium Board.

10.1. Monitoring and Evaluation, Impact Indicators, and Assessment

WHEAT 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 process associated with it.

Process evaluation will determine to what extent WHEAT has been implemented as planned, and will identify operational and strategic lessons for flexible and adaptive management. This will be done through process monitoring and performance assessments, which will require further analyzing and mapping of activities, milestones, outputs, and desirable outcomes. It will also define the role of R&D partners, based on available unrestricted and restricted funds and the annual work plan. Further refinement of WHEAT-wide and SI-specific impact pathways will continue to support process evaluation.

Process monitoring will include: semi-annual participatory reviews of milestones as a measure for project progress; virtual and annual face-to-face meeting of research partners; taking corrective measures if milestones are delayed. External technical experts will join face-to-face meetings.

Performance assessment will review the quality and quantity of outputs and outcomes, based on the evolution of Key Performance Indicators (Table 6).[5] Adoption of outputs by clients 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 SI-specific change—using Web-based surveys and stakeholder consultations that capture outcomes indicators.

[5] 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 will report their findings and recommendations to management as well as the Oversight Committee.

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 in collaboration with external experts and will evaluate how successful the CRP has been in meeting stated goals or objectives as described in Box 4.

The **first order impact** indicators for WHEAT 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 of and reduced workload for women. The **second order impacts** that may result in the long term will include: changes in 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 (e.g. 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; and 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, including with R&D partners and external reviewers, to inform and influence future courses of action. Alternative platforms, including a project website, scientific publications, review meetings, and regional workshops and conferences, will also be used to share the findings.

Priority setting will be based on targeting and ex-ante socioeconomic analysis undertaken by SI 1 as well as systematic feedback from clients, beneficiaries, and R&D partners. This is crucial for improving the understanding of context, constraints and high-payoff research strategies, and for adjusting current resource allocations to and within various SIs, thereby shaping priorities and enhancing the relevance and quality of WHEAT science. Priority setting and review will be implemented through SI-specific ex-ante impact analysis, expert panels, workshops, web platforms, and other means. Impact pathways leading to desired impacts—such as increases in crop productivity, farmers' income and food security, changes in local capacity and empowerment of women farmers—will be studied to foster desired changes and draw lessons for scaling out successes.

Using geo-referenced data from various CRPs and other SI data, WHEAT will provide a biennial update of impact pathways, the likely impacts of introducing available technologies, recommendation domains for different varieties and management practices, and projected impacts on poverty and gender groups—all to 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 in SI 1 of opportunities for future research and development investments.

Box 4. Details of impact assessment.

Impact assessment will be done by measuring the progress of tangible indicators affected (targeted) by the program and how they differ from the counterfactual situation without interventions. It will use recent advances in both qualitative methods (outcome mapping, narrative stories with key informants) and quantitative approaches (econometric, bio-economic modeling and general equilibrium modeling) to better understand the determinants of adoption and to evaluate the heterogeneous economic, social (poverty and gender), and environmental impacts of interventions on the target groups. These evaluations offer realistic assessment of returns to investment and allow extraction of 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; Shiferaw et al. 2008; Zilberman and Waibel 2007).

Given research-to-impact timelines, farm-level impact assessments during 2011–13 will establish baselines and monitor adoption in three primary project intervention areas in SI 2, as well as assessing past and ongoing impacts for SIs 4 and 5. This will be in addition to a rigorous gender audit for the entire WHEAT agenda. Impact assessment during 2014–16 will focus on SIs 2, 3, 6, and 8, while SIs 7, 9 and 10 will only be monitored at the level of output and outcomes.

Given the high costs and difficulties of establishing counterfactuals[8] in the field, data will be analyzed using propensity score matching (PSM) and double difference methods that 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) to serve as a counterfactual for estimating the attributable impact of the project on adopters (treatment group).[9] Where panel data from 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.

[8] A more detailed description of how WHEAT will address counterfactual and attribution issues in ex post impact assessment can be found in Annex E.

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

Table 6. Key performance indicators (KPIs) for WHEAT Strategic Initiatives (SIs).

												Disaggregation meaningful by		
	Indicator	**SI 1**	**SI 2**	**SI 3**	**SI 4**	**SI 5**	**SI 6**	**SI 7**	**SI 8**	**SI 9**	**SI 10**	**Gender**	**Country**	**Institution**
1	Number of documents/research articles and databases improving the definition of target, production constraints area, farmer needs, and prioritized research activities	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	
2	Number of users using WHEAT Portal, or accessing Web-based databases or CDs documenting germplasm, trial, or socioeconomic data, training modules, e-learning or IT tools	Yes	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		Yes	Yes
4	Number of institutions involved in collaboration for research and capacity building	Yes	Hubs	Yes	Collaborative evaluation & breeding				Yes	Yes	Yes	Yes	Yes	Yes
5	Number of development partners, farmers, and areas involved in CA and precision agricultural systems, in targeted peri-regional hubs		Yes	Yes							Yes	Yes	Yes	
6	Number of collaborative trial sets planted and reported		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes			Yes	Yes
7	Number of germplasm entities (advanced lines, segregating populations, genetic resources, introgression lines) developed and distributed to partners on request				Yes	Yes	Yes	Yes	Yes	Yes			Yes	Yes
8	Measures for genetic selection gains achieved every second year				Yes	Yes	Yes	Yes					Yes	
9	Number of variety releases and areas sown to CRP-derived germplasm				Yes	Yes	Yes		Yes				Yes	Yes
10	Quantity of seed scaled up by partners				Yes				Yes	Yes			Yes	

Table 6. Cont'd

	Indicator	**SI 1**	**SI 2**	**SI 3**	**SI 4**	**SI 5**	**SI 6**	**SI 7**	**SI 8**	**SI 9**	**SI 10**	**Disaggregation meaningful by**		
												Gender	Country	Institution
11	Germplasm bank accessions maintained using internationally recognized standards									Yes				Yes
12	Number of accessions genotyped using high-density markers and phenotyped (SNPs)				Yes	Yes	Yes	Yes		Yes				Yes
13	Number of key target genes sequenced across number of accessions					Yes	Yes	Yes		Yes				Yes
14	Documents/reports indicating use of WHEAT germplasm, tools, information	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes
15	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	Yes
16	MSc/PhD students graduating	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
17	Number of journal articles	Yes	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	Yes

10.2. Intellectual Property Management: Fostering Pre-competitive Networks Coupled with Healthy Downstream Competition

Networking is our strength: Each WHEAT SI relies on collaborative and participatory networks designed to generate outcomes for clients and impacts for beneficiaries. Partnerships among IARCs, ARIs, NARSs, regional organizations, farmers, civil society groups, private enterprises, donor organizations, and governments are being forged at (and along) various points of the wheat-value chain. These partnerships will develop and disseminate higher-yielding, stress-tolerant and disease-resistant cultivars with higher grain quality and better productivity, resiliency and sustainability.

Intellectual property (IP) as a tool to enable research and to reach clients: IP management is an enabling tool to generate and disseminate global public goods. In all its partnerships, including public-private, WHEAT will actively source the best technologies as inputs to accelerate R&D implementation and to speed deployment of global public goods and increase their humanitarian impacts. Our core approach in all collaborations includes upholding the rights to perform research, development, and deployment (RD&D) 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 RD&D collaborative networks in which WHEAT participates build a pre-competitive RD&D domain that encourages open availability and strong collaboration of R&D of bio-components, knowledge, and tools for the development of global public goods. During its implementation, WHEAT will encourage such “pre-competitive ag-commons” to the greatest extent possible. At the same time, WHEAT would benefit greatly from the development of a competitive domain to market products derived from pre-competitive domain outputs. New wheat varieties are often only slowly disseminated, due to a relatively low private R&D investment and the lack of a competitive edge for their deployment. By generating products attractive for private investment, such as hybrid wheat, WHEAT will engage both large and small commercial enterprises in the dissemination, deployment, and uptake of wheat agricultural solutions for the benefit of farmers and consumers in target countries.

Within the framework of established IP policies –such as those of CIMMYT, ICARDA, and sovereign states—competitive wheat products, market instruments (such as registration and certification schemes), protected IP rights and contracts, and non-restrictive business practices can provide investment incentives for commercial partners to work on much-needed, follow-on wheat innovation, with global spillover effects. In accordance with international regulations on plant genetic resources the implementers of WHEAT will thus strive for, and foment through IP management, a healthy combination of collaboration and competition in agricultural RD&D to effectively bridge the gap between generated seeds and technologies on one hand, and their efficient uptake by diverse clients on the other. Such strategies will generate the intended beneficial impacts on food security, poverty reduction, and environmental sustainability.

Regulatory frameworks for innovation in targeted regions: Existing regulatory frameworks for intellectual property, seed, and biosafety in targeted countries and markets may be friendly or hostile to the adoption and access of WHEAT products. Policies and rules posing barriers to (non-)transgenic varietal release, registration, and commercialization may stop an otherwise successful innovation process and block sorely needed impacts. WHEAT will work actively with pertinent regulatory authorities to arrive at a mutual understanding of issues such as biological and technical issues; seed markets and regulatory frameworks; training and capacity building for researchers and authorities on these areas; advocacy for the adoption of responsive regulatory standards and measures; and devising innovative and feasible mechanisms that facilitate entry of public-sector transgenics into the current costly and unreachable market for certified and transgenic crops.

Germplasm distribution: All wheat germplasm distribution from CIMMYT and ICARDA 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 may have enabled product development. 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, WHEAT will ensure that products emerging from such temporary or geographical competitive domains reach and benefit a significant number of poorer farmers. WHEAT 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.

10.3. Communication Strategy and Knowledge Management

WHEAT will rely on effective 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—WHEAT will use active and passive input to web platforms and cell phone technology to expand the range of opportunities for obtaining from clients and beneficiaries systematic feedback on the quality and relevance of its products. Examples of implementing new feedback mechanisms in the current agenda include uses of ICT tools described in SIs 3 and 5. Process evaluation and socioeconomic surveys will contribute to adjusting feedback approaches and capturing most relevant mechanisms as part of the key performance indicators (KPIs).

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

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

10.4. Assumptions

Policies and institutions

1. Unforeseen circumstances, such as soaring global prices associated with unprecedented demand for wheat 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 and an unimpeded access to field research sites.
4. Prices of fertilizers and other inputs do not escalate to where their application on staple crops is no longer affordable for smallholder farmers.
5. Government will implement policies supporting pre-release seed multiplication and accelerated variety release processes across regions and low-cost seed options.
6. Private companies, including those involved in seed business and information and communication technologies, will collaborate for the benefit of smallholder 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 and consider nutritional value and food safety as an important component of food security and trade enhancement.
9. Conducive policies and supportive institutions continue to consider nutritional value and food safety as an important component of food security and trade enhancement.

10. International travel and immigration policies remain stable.
11. Partner institutions agree with the vision of success and assist in fine-tuning impact targets.
12. Bureaucracy does not impede collaboration between institutions, and research collaboration between CGIAR centers and research partners is facilitated through the Consortium.
13. Decision makers understand and agree with the need to increase the investment in international agricultural research for important food crops.
14. Research and development institutions implement staff policies that motivate, reward, and retain highly-trained personnel.

Technologies

15. Transgenes shown to be effective for improving tolerance to drought, nutrition, efficiency of nitrogen use, and disease resistance in other crops in temperate environments and genetic backgrounds will have similar effects under severe stress in wheat.
16. Genes exist with large and consistent effects on drought and heat tolerance, yield potential, disease and pest resistance, and nutritional traits, and there are ways to implement effective screening methods for heat tolerance.
17. The Global Phenotypic Networks are properly coordinated, with no seed/data-tracking errors or poor trial designs, with no lag in flow of information, and with adequate precision of data.
18. Seed can be exchanged across country borders in reasonable timeframes and at reasonable costs.

Intellectual property

19. Multinational companies or advanced research institutions are willing to make available—for free or through affordable licenses--genes, traits, and technologies for the benefit of a large number of smallholder farmers.
20. The diversity data/knowledge generated from SI 9 is properly protected from appropriation by proprietary interests.

10.5. 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 WHEAT as a whole are:

1. **Financial 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, through both Consortium and non-Consortium sources, and 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 independent of the Consortium; broad-based advice and feedback opportunities; and effective approaches for decision-making and conflict resolution.

3. **"Domino effect" risk**: A particular failure of the CRP in a particular area, while not CRP-threatening in and of itself, could conceivably blow out of proportion to affect the CRP as a whole.
    - *Mitigating approach*: Strong safety and control standards for product releases, coupled with a steady and reliable communications function.

Technology change may also affect the CRP, and parts of it may be rendered obsolete by other parts. This may actually be a good development for the ultimate beneficiaries of the CRP, even if the CRP itself will have reduced impact.

11. Budget

WHEAT was developed to address challenges in the developing world where large numbers of poor people could be priced out of food due to increasing demands, inadequate crop productivity increases, climate change, natural resource scarcity and degradation. These challenges call for significantly increased investments and the WHEAT budget reflects this. For many years there has been underinvestment in germplasm-related research—in the CGIAR in general and wheat in particular—which is disproportional to the importance of wheat and the impact of wheat-related research for the poor (Evenson and Rosegrant 2002; Heisey et al. 2002; Lantican et al. 2005; Renkow and Byerlee 2010).

Not making these investments will contribute to the doubling of wheat prices, which will erode the purchasing power of approximately 1.2 billion wheat-dependent to 2.5 billion wheat-consuming poor. There is a strong likelihood of social unrest of an unprecedented magnitude if the already frail purchasing power of persistently large numbers of poor is further eroded by food and energy price-driven inflation. In South Asia, the combined challenges of climate change, decreasing water tables, and increasing demands of a growing population will leave one-seventh of the world's population with a deficit in their staple crop. In spite of rising global wheat prices, demand for the crop will increase by 21% by 2025 and 36% by 2050 (Rosegrant and Agcaoili 2010) while climate change will reduce wheat production likely by more than 16% by 2025 and by more than 30% by 2050 (see Box 1). *If research investments are not significantly increased now, the significant gaps in food supply will not be addressed in 15 years' time and will trigger further local wheat price increases.*

For WHEAT to mitigate these trends and make a pronounced positive impact on production, people, income, food security, and the environment (as summarized in Table 3), an estimated investment of USD 72.6 million in 2011, rising to USD 97.4 million in 2013, is required.

WHEAT partners will make every effort to obtain funding for the entire budget needed to implement the WHEAT agenda, through:

- Support from the Consortium via the CGIAR FUND.
- Bilateral funds aligned with the WHEAT 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 WHEAT agenda.
- Special fundraising efforts through the Borlaug Institute for South Asia (BISA). This is a joint initiative between the Government of India and CIMMYT to address the food security challenge in South Asia through a platform that strongly enhances cutting-edge joint research between international and South Asian scientists.

Financing scenarios

Given current funding available to the CGIAR, the Consortium requested two financing scenarios to be presented to the CGIAR. In addition to the full funding scenario, they are further described below:

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

Proposing these two funding scenarios does not imply endorsement of a WHEAT budget that is below the targeted funding of USD 97.4 million.

CGIAR Window 1-3 funding: Scenario 1 assumes that CGIAR Window 1-3 increases annually at 5% over 2010 in the case of CIMMYT and GCP and 10% over 2009 in the case of ICARDA, and also provides all management costs associated with CGIAR Window 1-3 funding**.** Scenario 2 assumes that CGIAR Window 1-3 increases annually at 5% over 2010 and also provides all management costs associated with implementing this CGIAR Research Program.

Bilateral funding: Scenarios 1 and 2 assume that bilateral funding increases by 5% annually, using 2011 as a base. Estimates are aligned with those compiled by the Consortium in October 2010. Actual bilateral funding increases were 7% in 2010 (current budgets) and 7% in 2011 (current contracts and contracts whose total value has been confirmed by donors but are not yet signed).

The summary results of the four scenarios are presented in Table 7, with more details provided for each scenario in Tables 8A to 8C. Scenario 1 and 2 bring WHEAT to 50% and 52% of full funding, with proportions of CGIAR Window 1-3 operational funding of 36% and 39%, respectively, as compared to 31% in 2009 and 35% in 2010.

Table 7. Financing scenarios for WHEAT.

million USD over three years (2011 - 2013)	**Scenario 1**	**Scenario 2**	**Full funding**
Total Budget	113.9	118.7	227.5
Total Budget in proportion of full funding	50%	52%	100%
Total CGIAR Window 1-3 unrestricted	41.0	45.8	75.1
Proportion CGIAR Window 1-3	36%	39%	33%
Total Bilateral funding	72.9	72.9	152.5
Proportion Bilateral	64%	61%	67%
Influence of CGIAR Window 1-3 on research agenda	30%	33%	27%

Budgeted years 2009 and 2010 (Tables 8A, 8B and 8C) provide an indicative baseline of past spending, distributed retrospectively amongst the newly proposed Strategic Initiatives. From 2011 onwards, projected budgets are optimized for the implementation of WHEAT.

Scenario 1 (Table 8A) is a risk 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 WHEAT at risk due to lack of funding for the CGIAR mandated oversight and management components. Also at 5% budget growth and 6% new management, research funding for 2011 -2013 under this scenario remains barely at par with inflation which will not be conducive to address the immense global challenges to food security and natural resource management. The proponents of WHEAT think that WHEAT-wide streamlined management approaches have a great potential to reduce oversight and management costs in the medium term. It will however not happen in the first three years.

Scenario 2 (Table 8B) proposes that all management costs of implementing WHEAT be paid through the 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 unrestricted funding freed up for research. This scenario increases the CGIAR Window 1-3 proportion of operational funding to 39% which is above the CGIAR average of 33% (in 2010). It enables WHEAT to be implemented at 52% of the total funding needed, and ensures that the budget for managing WHEAT is available to lead it through a transition period where a rationalization of management activities between the CRP and bilateral programs can be pursued.

Full funding (Table 8C) assumes complete funding of WHEAT and lower the proportion of the CGIAR Window 1-3 commitment to the operational costs of WHEAT to a CGIAR-wide average of 33%. This scenario requires substantially increased funding for the entire period 2011–2013.

Expenses

Tables 8A, 8B, and 8C show the proposed allocation of expenses by Strategic Initiative, Institution or Program, and Category; they also contain further break-downs of WHEAT management costs. Given funding insecurities and the high level of bilateral funding, the future budget break-down is very much dependent on WHEAT receiving funding aligned with its strategy.

Table 8A. Income and expenses for Scenario 1 "CGIAR Baseline 5%" (USD '000).

Scenario 2 "CGIAR Baseline 5%"	2009	2010	2011	2012	2013	Total 2011-13	Percent 2011-13	Comments
Income operational								
CGIAR Window 1-3: Reserch	8,949	11,675	12,259	12,872	13,516	38,647	34%	5% increase 2011-13
CGIAR Window 1-3: CRP Management	0	0	490	515	541	1,546	1%	
CGIAR Window 1-3: Consortium Board/FUND	0	0	245	257	270	773	1%	
Bilateral funding secured	20,240	21,598	9,030	863	394	10,287	9%	
New bilateral funding (pipeline)	0	0	14,100	23,424	25,108	62,632	55%	
Proportion CGIAR Window 1-3	31%	35%	36%	36%	36%	36%		
Total Income Operational	**29,189**	**33,273**	**36,125**	**37,931**	**39,828**	**113,885**	**100%**	**50% of full funding**
Expenses by Strategic Initiative			**Optimized allocation**					
SI 1 Technology targeting for greatest impact	893	1,699	2,631	2,763	2,901	8,295	7%	
SI 2 Susteinable wheat-based systems	1,920	3,321	2,625	2,756	2,894	8,274	7%	
SI 3 Nutrient and water- use efficency	499	822	1,346	1,413	1,484	4,243	4%	
SI 4 Productive wheat varieties	8,502	8,057	9,124	9,580	10,059	28,763	25%	
SI 5 Durable disease and pest resistance	5,253	5,156	5,991	6,290	6,605	18,885	17%	
SI 6 Enchanced heat and drought tolerance	3,455	4,079	3,470	3,643	3,825	10,938	10%	
SI 7 Breaking the yield barrier	806	1,483	1,396	1,466	1,539	4,402	4%	
SI 8 More and better seed	1,639	2,347	1,153	1,210	1,271	3,634	3%	
SI 9 Seeds of discovery	3,421	3,597	3,728	3,756	3,944	11,278	10%	
SI 10 Strengthening capacities	2,799	2,711	2,645	2,777	2,916	8,339	7%	
CRP Management	0	0	1,445	1,517	1,593	4,555	4%	
Consortium Board/FUND	0	0	723	759	797	2,278	2%	
CRP Total	**29,189**	**33,273**	**36,125**	**37,931**	**39,828**	**113,885**	**100%**	
Expenses by Institution or Program			**Based on 2009-2010 proportions**					
CIIMYT	18,210	21,997	21,859	22,952	24,099	68,909	61%	
GCP	0	0	0	0	0	0	0%	
ICARDA	6,658	6,991	7,420	7,791	8,181	23,393	21%	
Partners	4,321	4,285	4,679	4,913	5,158	14,749	13%	
CRP Management	0	0	1,445	1,517	1,593	4,555	4%	
Consortium Board/FUND	0	0	723	759	797	2,278	2%	
Total	**29,189**	**33,273**	**36,125**	**37,931**	**39,828**	**113,885**	**100%**	
Expenses by Category			**Based on 2009-2010 proportions**					
Personnel Costs	9,167	10,450	11,118	11,674	12,258	35,523	31%	
Supplies and Services	8,672	9,886	10,519	11,045	11,597	33,607	29%	
Travel	1,543	1,759	1,872	1,965	2,063	5,980	5%	
Workshops/Conferences/Training	810	923	982	1,031	1,083	3,138	3%	
Collaborators	4,022	4,584	4,878	5,122	5,378	15,584	14%	
Depreciation and Capital Expenditures	946	1,079	1,148	1,205	1,265	3,667	3%	
Institutional Manegement	4,029	4,593	4,887	5,131	5,388	15,613	14%	
Consortium Board/FUND	0	0	723	759	797	2,278	2%	
Total	**29,189**	**33,273**	**36,125**	**37,931**	**39,828**	**113,885**	**100%**	
CRP-specific Management								
CRP leadership and meetings	0	0	650	683	717	2,049	45%	
MC & Advisory Board	0	0	95	100	105	299	7%	
CRP Knowledge management	0	0	350	368	386	1,103	24%	
CRP Monitoring and Evaluation	0	0	350	368	386	1,103	24%	
Total	**0**	**0**	**1,445**	**1,517**	**1,593**	**4,555**	**100%**	

Table 8B. Income and expenses for Scenario 2 "CGIAR Baseline 5% + New Management" (USD '000).

Scenario 1 "CGIAR Baseline 5%+New Management"	2009	2010	2011	2012	2013	Total 2011-13	Percent 2011-13	Comments
Income								
CGIAR Window 1-3: Research	8,949	11,675	12,259	12,872	13,516	38,647	33%	5% Increase 2011-13
CGIAR Window 1-3: CRP Management	0	0	1,506	1,581	1,660	4,747	4%	All management
CGIAR Window 1-3: Consortium Board/FUND	0	0	753	791	830	2,374	2%	All management
Bilateral funding secured	20,240	21,598	9,030	863	394	10,287	9%	
New bilateral funding (pipeline)	0	0	14,100	23,424	25,108	62,632	53%	
Proportion CGIAR Window 1-3	31%	35%	39%	39%	39%	39%		
Total Income Operational	**29,189**	**33,273**	**37,649**	**39,531**	**41,508**	**118,687**	**100%**	**52% of full funding**
Expenses by Strategic Initiative			**Optimized allocation**					
SI 1 Technology targeting for greatest impact	893	1,699	2,742	2,879	3,023	8,645	7%	
SI 2 Susteinable wheat-based systems	1,920	3,321	2,735	2,872	3,016	8,623	7%	
SI 3 Nutrient and water use efficency	499	822	1,403	1,473	1,546	4,422	4%	
SI 4 productive wheat varieties	8,502	8,057	9,509	9,984	10,483	29,976	25%	
SI 5 Durable disease and pest resistance	5,253	5,156	6,243	6,555	6,883	19,682	17%	
SI 6 Enchanced heat and drought tolerance	3,455	4,079	3,616	3,797	3,987	11,399	10%	
SI 7 Breaking the yield barrier	806	1,483	1,455	1,528	1,604	4,587	4%	
SI 8 More and better seed	1,639	2,347	1,201	1,261	1,324	3,787	3%	
SI 9 Seeds of discovery	3,421	3,597	3,728	3,915	4,111	11,754	10%	
SI 10 Strengthening capacities	2,799	2,711	2,757	2,895	3,039	8,691	7%	
CRP Management	0	0	1,506	1,581	1,660	4,747	4%	
Consortium Board/FUND	0	0	753	791	830	2,374	2%	
CRP Total	**29,189**	**33,273**	**37,649**	**39,531**	**41,508**	**118,687**	**100%**	
Expenses by Institution or Program			**Based on 2009-2010 proportions**					
CIIMYT	18,210	21,997	22,780	23,919	25,115	71,815	61%	
GCP	0	0	0	0	0	0	0%	
ICARDA	6,658	6,991	7,733	8,120	8,526	24,380	21%	
Partners	4,321	4,285	4,876	5,120	5,376	15,371	13%	
CRP Management	0	0	1,506	1,581	1,660	4,747	4%	
Consortium Board/FUND	0	0	753	791	830	2,374	2%	
Total	**29,189**	**33,273**	**37,649**	**39,531**	**41,508**	**118,687**	**100%**	
Expenses by Category			**Based on 2009-2010 proportions**					
Personnel Costs	9,167	10,450	11,587	12,166	12,775	36,528	31%	
Supplies and Services	8,672	9,886	10,962	11,510	12,086	34,559	29%	
Travel	1,543	1,759	1,951	2,048	2,150	6,149	5%	
Workshops/Conferences/Training	810	923	1,023	1,075	1,128	3,227	3%	
Collaborators	4,022	4,584	5,083	5,338	5,604	16,025	14%	
Depreciation and Capital Expenditures	946	1,079	1,196	1,256	1,319	3,770	3%	
Institutional Management	4,029	4,593	5,093	5,347	5,615	16,055	14%	
Consortium Board/FUND	0	0	753	791	830	2,374	2%	
Total	**29,189**	**33,273**	**37,649**	**39,531**	**41,508**	**118,687**	**100%**	
CRP-specific Management								
CRP leadership and meetings	0	0	650	682	717	2,049	43%	
MC & Advisory Board	0	0	100	105	110	315	7%	
CRP Knowledge Management	0	0	376	395	415	1,185	25%	
CRP Monitoring and Evaluation	0	0	380	399	419	1,198	25%	
Total	**0**	**0**	**1,506**	**1,581**	**1,660**	**4,748**	**100%**	

Table 8C. Income and expenses under "Full Funding" (USD '000).

Full Funding	2009	2010	2011	2012	2013	Total 2011-13	Percent 2011-13	Comments
Income								
CGIAR Window 1-3: Research	8,949	11,675	15,873	20,346	25,219	61,438	27%	
CGIAR Window 1-3: CRP Management	0	0	2,352	3,014	3,736	9,102	4%	
CGIAR Window 1-3: Consortium Board/FUND	0	0	1,176	1,507	1,868	4,551	2%	
Bilateral funding secured	20,240	21,598	9,030	863	394	10,287	5%	
New bilateral funding (pipeline)	0	0	30,359	49,624	62,188	142,171	62%	
Proportion CGIAR Window 1-3	31%	35%	33%	33%	33%	33%		Average CGIAR
Total Income Operational	**29,189**	**33,273**	**58,791**	**75,354**	**93,405**	**227,549**	**100%**	**Full funding**
Expenses by Strategic Initiative			**Optimized allocation**					
SI 1 Technology targeting for greatest impact	893	1,699	4,282	5,489	6,803	16,574	7%	
SI 2 Susteinable wheat-based systems	1,920	3,321	4,271	5,475	6,786	16,532	7%	
SI 3 Nutrient and water use efficency	499	822	2,190	2,808	3,480	8,478	4%	
SI 4 productive wheat varieties	8,502	8,057	14,848	19,032	23,590	57,470	25%	
SI 5 Durable disease and pest resistance	5,253	5,156	9,749	12,496	15,489	37,734	17%	
SI 6 Enchanced heat and drought tolerance	3,455	4,079	5,647	7,237	8,971	21,855	10%	
SI 7 Breaking the yield barrier	806	1,483	2,272	2,912	3,610	8,795	4%	
SI 8 More and better seed	1,639	2,347	1,876	2,405	2,981	7,261	3%	
SI 9 Seeds of discovery	3,421	3,597	5,822	7,463	9,250	22,535	10%	
SI 10 Strengthening capacities	2,799	2,711	4,305	5,518	6,839	16,662	7%	
CRP Management	0	0	2,352	3,014	3,736	9,102	4%	
Consortium Board/FUND	0	0	1,176	1,507	1,868	4,551	2%	
CRP Total	**29,189**	**33,273**	**58,791**	**75,354**	**93,405**	**227,549**	**100%**	
Expenses by Institution or Program			**Based on 2009-2010 proportions**					
CIIMYT	18,210	21,997	35,573	45,595	56,517	137,685	61%	
GCP	0	0	0	0	0	0	0%	
ICARDA	6,658	6,991	12,076	15,478	19,186	46,741	21%	
Partners	4,321	4,285	7,614	9,759	12,097	29,470	13%	
CRP Management	0	0	2,352	3,014	3,736	9,102	4%	
Consortium Board/FUND	0	0	1,176	1,507	1,868	4,551	2%	
Total	**29,189**	**33,273**	**58,791**	**75,354**	**93,405**	**227,549**	**100%**	
Expenses by Category			**Based on 2009-2010 proportions**					
Personnel Costs	9,167	10,450	18,094	23,192	28,747	70,033	31%	
Supplies and Services	8,672	9,886	17,118	21,941	27,197	66,257	29%	
Travel	1,543	1,759	3,046	3,904	4,839	11,789	5%	
Workshops/Conferences/Training	810	923	1,598	2,049	2,539	6,186	3%	
Collaborators	4,022	4,584	7,938	10,174	12,612	30,724	14%	
Depreciation and Capital Expenditures	946	1,079	1,868	2,394	2,967	7,229	3%	
Institutional Management	4,029	4,593	7,953	10,193	12,635	30,781	14%	
Consortium Board/FUND	0	0	1,176	1,507	1,868	4,551	2%	
Total	**29,189**	**33,273**	**58,791**	**75,354**	**93,405**	**227,549**	**100%**	
CRP-specific Management								
CRP leadership and meetings	0	0	900	1,150	1,411	3,461	38%	
MC & Advisory Board	0	0	105	115	125	345	4%	
CRP Knowledge Management	0	0	672	874	1,100	2,646	29%	Can be direct costed
CRP Monitoring and Evaluation	0	0	675	875	1,100	2,650	29%	Can be direct costed
Total	**0**	**0**	**2,352**	**3,014**	**3,736**	**9,102**	**100%**	

Expenses by Strategic Initiative: The proposed allocation of expenses by Strategic Initiative was assessed by CIMMYT, ICARDA, and the GCP 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 3) and through more systematic prioritization by stakeholders. The significant level of bilateral funding to WHEAT may complicate the optimal allocation of funds among Strategic Initiatives unless funds can be sourced that are very much aligned with the WHEAT Strategy, or FUND members transform restricted, bilateral funding into CGIAR Window 1-3 unrestricted funding.

The more donors restrict their funding to particular projects or activities, the greater will be the potential variation from the budgeted, optimal allocation of funds. For example, it seems like support to 'SI 8 More and better seed' should be decreased. Indeed a significant proportion of SI 8 related resources currently pay for producing foundation seed for short-term impact. The same or even fewer resources could be used much more effectively for research which has greater leverage and more medium-term impact.

As requested by the Consortium, costs determined as "essential" for the conservation of wheat genetic resources have been removed from the WHEAT budget scenarios. SI 9 will add value to the collections held by CIMMYT and ICARDA by leveraging top-end genomic and phenotypic technologies to uncover the genetic heritage of wheat but it does not cover the gene banks operational expenses.

Expenses by region: WHEAT is a global collaborative program where the same research outputs will generate outcomes and impact in several political regions. While resources are hence not allocated by region, WHEAT has variable importance for various regions—a fact that needs consideration in future priority setting and focus of the WHEAT agenda. One region in particular stands out: South Asia where a large proportion of poor wheat farmers and consumers live (FAOSTAT 2010), highlighted in Table 9. If funds are short, investments targeted at solving the challenges in this region will need particular attention.

Expenses by institution or program: These are based on 2009–2010 averages. Improved estimates can only be made once improved information on funding is available, given that the proportion of partner funding strongly varies among bilateral projects and Strategic Initiatives. Budget allocations among CIMMYT, ICARDA, and partners in 2009 and 2010 were 64%, 22%, and 14%, respectively. The Generation Challenge Program contributed 4% of the available 2009 and 2010 budget of WHEAT, and all of that is allocated to Generation Challenge Program partners, indicating zero resources to the Generation Challenge Program from WHEAT but contributing to partners' budgets. Strategically, partners' budgets will increase/decrease to the extent they can/cannot provide high-quality outputs or innovation at lower research-PLUS-transaction costs.

Expenses by category: These are based on 2009–2010 averages. Institutional management costs are 15% for CIMMYT and 19% for ICARDA, and averaged in proportion to each institution's budget.

Breakdown of WHEAT management costs: It is assumed that 2% of the overall budget for WHEAT is reassigned to the Consortium to cover Systems costs. In case this proportion changes, so will the budgets for Scenarios 1 and 2. It is estimated that WHEAT will require 4% additional management investment that will not be covered by institutional overheads and cannot be assigned to current contracts of bilateral projects. The budget will cover the costs for CRP leadership and meetings (assuming alignment of meetings with bilateral projects), costs by the Management Committee and Oversight Committee, knowledge management across WHEAT, and monitoring and evaluation beyond impact assessment done in SI 1 Socioeconomics and policies for wheat futures. In the course of executing WHEAT, management costs associated with knowledge management and M&E will likely be the easiest to direct-cost. Direct costing of other management costs will be possible to the extent bilateral donors agree to adopt the oversight mechanism of WHEAT for their own projects and meetings can be consolidated. In general, management costs imply a very high level of direct costing of activities.

Table 9. Relevance of wheat in various regions of the developing world (based on FAOSTAT 2010).

	Relevance of wheat for various target regions				
Description	**Africa**	**E&SE Asia**	**S Asia**	**CWANA**	**LAC**
Wheat area	2%	21%	39%	31%	8%
Wheat production	2%	34%	35%	22%	7%
Population	13%	33%	33%	10%	10%
Poor < 1 USD	26%	21%	46%	3%	5%
Poor < 2 USD	19%	24%	48%	4%	5%
Wheat kcal < 1 USD	9%	31%	52%	4%	4%
Wheat kcal < 2 USD	6%	32%	49%	8%	4%

12. References

General

Abdelali-Martini, M., Goldey, P., Jones, G. and Bailey, E. 2003. Towards a feminization of agricultural labour in northwest Syria. *Journal of Peasant Studies* 30(2): 71–94.

Alwang, J. and Siegel, B.P. 2003. Measuring the impacts of agricultural research on poverty reduction. *Agricultural Economics* 29: 1–14.

Alston, M.J., Norton, W.G. and Pardey, P.G. 1995. Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. Cornell University Press, Ithaca and London.

Baker, J.L. 2000. Evaluating the impacts of development projects on poverty. A handbook for practitioners. World Bank. Washington DC. 230 pp.

Battisti, D.S. and Naylor, R.L. 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science* 9:323 no. 5911 pp 240–244.

Balakrishnan, R. and Fairbairn-Dunlop, P. 2005. Rural women and food security in Asia and the Pacific: Prospects and paradoxes. FAO, Regional Office for Asia and the Pacific, Bangkok.

Braun, H.J., Atlin, G. and Payne, T. 2010. Multi-location testing as a tool to identify plant response to global climate change. In: Reynolds, CRP. (ed.). Climate Change and Crop Production, CABI, London, UK.

Byerlee, D. and Dubin, J. 2009. Crop Improvement in the CGIAR as a Global Success Story of Open Access and International Collaboration. Proceedings of the International Conference on the Microbial Commons. Ghent, Belgium, 12–13 June 2009.

CGIAR 2009. Towards a Strategic and Results Framework for the CGIAR. November 18, 2009. (http://www.cgiar.org/pdf/Business%20Meeting%202009/cgiar_bus_mtg_2009_srf-mp.pdf)

Charmet, G., 2009. Les causes du plafonnement du rendement en grandes cultures. INRA. Presented to the 2009 Salon International de l'Agriculture.

Cobb-Clark, D. and Crossely T. 2003. Econometrics for evaluation: An introduction to recent developments. *The Economic Record* 79 (247): 491–511.

Cordell, D., Neset, T. S. S., Drangert, J.-O. and White, S. 2010. Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand. In: Don Mavinic, Ken Ashley and Fred Koch (eds). Proceedings of the International Conference on Nutrient Recovery from Wastewater Streams, Vancouver, 2009. IWA Publishing, London, UK.

Dixon, J., Braun, H.-J. and Crouch, J. 2009. Transitioning wheat research to serve the future needs of the developing world. In: Dixon, J., Braun, H.-J. and Kosina, P. (eds). Wheat Facts and Futures 2009, 1–19. Mexico, D.F.: CIMMYT.

Douthwaite, B., Schulz, S., Olanrewaju, A. and Ellis-Jones, J. 2007. Impact pathway evaluation of an integrated *Striga hermonthica* control project in northern Nigeria. *Agricultural Systems* 92: 201–222.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.-F., Schmidhuber, J. and Tubiello, F.N. 2007. Food, fibre and forest products. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Multi-location Testing to Identify Plant Response 137. Cambridge University Press, Cambridge, UK, 273–313.

Eriyagama, N., Smakhtin, V. and Gamage, N. 2009. Mapping drought patterns and impacts: A global perspective. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Evenson, R. E. and Rosegrant, M. 2002. The economic consequences of crop genetic improvement programmes. In: Robert E. Evenson and Douglas Gollin (eds.). Crop Variety Improvement and its Effect on Productivity: The Impact of International Agricultural Research. Wallingford, Oxon: CABI Publishing.

Expert Panel on the Stem Rust Outbreak in Eastern Africa 2005. Sounding the alarm on global stem rust: An assessment of Race 99 in Kenya and Ethiopia and the potential for impact in neighboring regions and beyond. Internal CIMMYT document.

FAO 2005. Plant breeding and related biotechnology capacity assessments. (http://gipb.fao.org/Web-FAO-PBBC/index.cfm?where=01).

FAOSTAT 2008 and 2010. http://faostat.fao.org/

Fischer, G. 2009. World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability? Paper prepared for the expert meeting “How to feed the world in 2050”. FAO, 24–26 June 2009.

Heffer, P. 2009. Assessment of Fertilizer Use by Crop at the Global Level 2006/2007-2007/08. International Fertilizer Industry Association. Paris: IFA. http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database.html/Assessment-of-Fertilizer-Use-by-Crop-at-the-Global-Level-2006-07-2007-08.html2

Heisey, P.W., Lantican, M.A. and Dubin, H.J. 2002. Impacts of international wheat breeding research in developing countries, 1966–1997. Mexico, D.F.: CIMMYT. Available on line at http://www.cimmyt.org/Research/ Economics/map/impact_studies/wheat1966_97/WhtImpacts66_97.pdf.

IPCC 2007. Climate Change 2007: The Physical Science Basis. In: Salomon, S., Quin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., and Miller, H.D. (eds). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Lantican, M.A., H.J. Dubin, and M.L. Morris 2005. Impacts of international wheat breeding research in the developing world, 1988–2002. Mexico, D.F.: CIMMYT

Lipton, M. 2005. The family farm in a globalizing world: The role of crop science in alleviating poverty. 2020 Policy Brief No. 74, International Food Policy Research Institute, Washington, D.C.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. 2008. Supporting Online Material for: Prioritizing Climate Change Adaptation Needs for Food Security in 2030. www.sciencemag.org/cgi/content/full/319/5863/607/DC1. DOI: 10.1126/science.1152339.

Long, S., Xin-Guang Zhu, S.L. Naidu and D. R. ort. 2006. Can improvement in photosynthesis increase crop yields? Plant, Cell and Environment, 29: 315-330.

Moyo, S., Norton, G.W., Alwang, J., Rhinehart, I. and Demo M.C. 2007. Peanut research and poverty reduction: impacts of variety improvement to control peanut viruses in Uganda. *American Journal of Agricultural Economics* 89(2): 448–460.

OECD-FAO, 2009. Agricultural Outlook 2009-2018. www.agri-outlook.org

Ortiz, R., Sayre, K.D., Govaerts, B. Gupta, R., Subbarao G.V., Ban, T., Hodson, D., Dixon, J.M., Ortiz-Monasterio, J.I. and Reynolds, M. 2008. Climate change: Can wheat beat the heat? Agriculture, Ecosystems & Environment 126: 46-58.

Renkow, M. and D. Byerlee (2010) The impacts of CGIAR research: A review of recent evidence. Food Policy, 35: 391-402.

Roberts, T. 2008. Improving Nutrient Use Efficiency. Turk J. Agric For 32:177-182.

Rosegrant, M. W. and Agcaoili, M. 2010. Global food demand, supply, and price prospects to 2010. International Food Policy Research Institute, Washington, D.C. USA.

Shiferaw, B., Kebede, T.A. and You, Z. 2008. Technology adoption under seed access constraints and the economic impacts of improved pigeonpea varieties in Tanzania. *Agricultural Economics* 39: 1–15.

Smale, Melinda, Diakité, Lamissa, Dembélé, Brahima, Traoré, Issa Seni, Guindo, Oumar and Konta, Bouréma 2008. Trading millet and sorghum genetic resources: women vendors in the village fairs of San and Douentza, Mali. IFPRI Discussion Paper No. 746, International Food Policy Research Institute, Washington, DC.

Wooldridge, J.M. 2002. Econometric analysis of cross section and panel data. Cambridge, Mass.: The MIT Press.

Woolley, J., Ribaut, J.-M., Bouis, H. and Adekunle, A. 2009. The CGIAR’s Challenge Program experiences: a critical analysis. Paper prepared for the CGIAR Strategy and Results Framework Mega-Program Meeting, Rome, February 17–20, 2009.

World Bank 2008. World Development Report, 2008. Washington, D.C.: The World Bank.

World Bank, Food and Agriculture Organization and International Fund for Agricultural Development 2009. Gender in agriculture sourcebook. Washington, DC: World Bank.

You, L., M. W. Rosegrant, S. Wood and D. Sun, 2009. Impact of growing season temperature on wheat productivity in China. Agricultural and Forest Meteorology 149 (2009) 1009–1014

Zilberman, D. and Waibel, H. (eds) 2007. International Research on Natural Resource Management: Advances in Impact Assessment. Wallingford, UK: FAO and CAB International.

Part 2 -- WHEAT Strategic Initiatives

At the core of WHEAT are ten Strategic Initiatives (SIs). Of high priority for international wheat research, and reflecting partners' feedback, the SIs are designed for integrated implementation to generate products and service that meet the needs and aspirations and leverage the capacities of regional and local research and development partners and smallholder farmers in the target groups to produce more food for rural and urban consumers.

The SIs provide the underpinning information and knowledge base - the science drivers for improvement – that cover the range of the most important science interventions that can make the crop more productive and robust to meet the production challenges ahead. These have been identified as new and novel selection methods (using genomic and physiological tools) and agronomy (conservation agriculture) technologies, new and novel characterized germplasm for faster and more effective genetic improvement (land-races, synthetics, alien variation), and information for more effective needs assessment, targeting and adoption. This integration of science disciplines allows the benefits of novel science to impact quickly on crop improvement to work for poverty alleviation in a way that provides productivity gains with no extra costs to the farmer and is the most efficient pathway for poverty alleviation in the target regions.

WHEAT exploits the extensive experience and skills base of the partners in a coherent way, and links these into the international wheat research and technology development community through the interactions with external public and private partners. The SIs are individually coherent in terms of discipline (socioeconomics, physiology, agronomy, plant pathology, genomics, genetics, cytogenetics, chemistry) but are linked through the common theme of the identification and fast adoption and deployment of new genetic combinations adapted to new agronomy technologies in target environments identified for greatest impact.

Strategic Initiative 1. Technology targeting for greatest impact

Value proposition

Enhance the effectiveness and impact of WHEAT research through better targeting of new technologies, strategic analysis and institutional innovations that enhance gender-differentiated impacts and strengthen linkages between stakeholders along the wheat input-output value chain.

Estimated impact	
Benefits to scientists and partners	Better targeting of technologies, more informed breeding, and better policies for impact and price stabilization; better priority setting, gender mainstreaming, and improved policies for sustainable and inclusive growth.
Benefit to the poor	More relevant wheat innovations and earlier access to them. Higher income for smallholders and staple food prices and cheaper food for consumers.
Benefit to the environment	More sustainable intensification of more diverse wheat-based systems. Reduced pressure on marginal environments.
Others	Positive spillovers to other research within national and global programs.

Justification

General background

Poverty remains a concern in many wheat dependent regions, notably South Asia (See Table 1). Future shocks – population growth, declining access to inputs, global climate change, and others – threaten to further challenge the livelihood security and food access by vulnerable populations that are the primary target beneficiaries of WHEAT (see Chapter 1). Much can be learned from past successes in increasing wheat productivity and production, but crucial questions remain regarding why these successes have not been uniformly or universally realized, why rates of yield gain have not been maintained in all regions, how recent wheat price hikes can be prevented and food prices stabilized, and how WHEAT research can be better prioritized and focused to redress some of these concerns.

Improved wheat production has saved millions of lives in the developing world, mainly in the Green Revolution belts of South Asia, China, West Asia, and Latin America. The dramatic productivity growth and steady increase in wheat production were made possible through technological achievements resulting in the development of high-yielding semi-dwarf varieties—assisted by favorable policy and institutional support to ensure farmers had access to the new seeds as well as fertilizer, markets, and irrigation infrastructure. Some evidence shows that about two-thirds of the productivity growth arose from improved agronomy coupled with policy and institutional support, which made it possible for farmers to use fertilizer and seeds, control weeds, and access markets (Evenson and Gollin 2003). This benefited farmers through lower costs of production, improved market access and better prices, and poor consumers benefited from sustained low food prices—all leading to an unprecedented fall in poverty and hunger.

The early, improved varieties spread rapidly over the high-potential production areas, which led to widespread adoption in South Asia (especially in irrigated areas) followed by rainfed areas of Latin America. This integrated approach, linking technological progress with appropriate support systems to deliver information, seeds, fertilizer, marketing services, and financial credit to farmers boosted average yields during 1966–79 by 3.6% per annum in developing countries. However, this level of productivity growth was not sustained—it slipped to 2.8% per annum during 1984–94 and dropped to 1.1% during 1995–2005. This has been a worrisome development for food security in many developing regions where wheat remains the major staple crop. Wheat accounts for about 25% of the daily calorie needs in India and China and about 17% for all developing countries.

Slowing productivity growth is further complicated by changing consumption patterns, the threat of climate change, and increasing reliance on rainfed systems, all of which escalate supply and market risks. In the last two years, inelastic demand, depleted physical stocks, focus on production in a few "breadbaskets," and the over-reactions of governments and financial markets have brought the world to a situation where relatively small, weather-related production shortfalls in a single breadbasket leads to large price fluctuations with worrisome impact on poor consumers and social stability. An overambitious reliance on production in a few breadbaskets and trade has come along with greater risks for supply shortfall and price instability.

The food demand for wheat has been increasing in many countries, including many in Africa, and is projected to grow by 2.6% per annum until 2020. Even though developing countries produce 67% of all wheat and contribute about 33% of the net export, wheat now accounts for the largest food imports (43%) to developing countries (Dixon et al. 2009). Meeting these challenges requires a reorientation of research to today's food price and production realities, and on institutional innovations and policies that can improve wheat markets and deliver improved technologies and services more effectively to smallholder producers, with a particular focus on women farmers who have inadequately benefited from past research.

Wheat farming systems in South Asia are projected to suffer most from heat stress and water scarcity due to climate change, with annual wheat production losses of USD 7 billion by 2025. Deepening our understanding of vulnerabilities, and promoting effective mechanisms for adaptation to and mitigation of climate change impacts, will require new socioeconomics and policy research. With increasing drought incidence and water scarcity for irrigation, wheat is likely to be grown increasingly under rainfed conditions—indicating geographical shifts in production regions. This will escalate the risks faced by small-scale producers and expose poor consumers to stronger price fluctuations. Although several rainfed areas have benefited from drought-tolerant varieties, technology adoption in rainfed and other risky growing regions has generally been slow, lagging behind other areas.

In Africa, wheat is now the fastest growing single commodity demanded by consumers in urban areas and accounts for largest food imports into the continent. Lack of a systematic economic analysis of the future of wheat and the potential for competitive wheat production in the sub-Saharan region has led to sheer neglect (with few exceptions) of the sector in R&D efforts. Diagnosis of constraints, identifying new opportunities, and designing, developing, and deploying future technologies (water-efficiency, drought-tolerance and sustainable practices) would require strategic foresight and research on proper targeting and institutional and policy analysis to secure the future of wheat farmers and global and regional food security.

Why international agricultural research?

Although wheat is a well-traded crop, most of the wheat consumed in the developing world is produced locally. Recent price shocks call for a new focus on understanding wheat markets and risk realities. They also highlight the need to revise our vision of where future and stable wheat supplies will come from. Compared to the developed world, where farmer practice is closer to its optimum, there is yet much prospect to increase wheat productivity and value chains in the developing world, and to diversify risk by increasing the competitiveness of a greater number of wheat production areas. As a result, SI1 will target wheat-related interventions to generate the greatest impact on the poor, women and children, and—in collaboration with the CGIAR Research Program CRP 2 'Policies, institutions, and markets for enabling agricultural incomes for the poor'—explore policy interventions that stabilize and establish fair wheat grain prices.

How will we achieve this?

The future of increased and more stable wheat production in the developing world depends on new varieties and management practices to meet the demand from differentiated value chains, address the negative impacts of climate change, and reverse the stagnating productivity trends in the post-Green Revolution areas. All of these imply better institutional innovations, markets, and policies to replace outdated varieties with modern cultivars and stimulate farmer investments in sustainable crop, soil, and water management (Byerlee and Traxler 1995).

The overall objective of SI 1 is to provide a social science context for WHEAT and to complement and enhance the relevance and effectiveness of the work in the other SIs. The SI will conduct strategic socioeconomics research on wheat systems while ensuring coherent research with the other WHEAT SIs to support priority setting, targeting and technology development and deployment. As a result, SI1 will generate knowledge, data, tools, institutional innovations and policy options, while actively enabling their use in other SIs to enhance farmer access to technologies and markets for sustainable productivity growth and food security. Together with CRP2, SI1 will assess the effect of production and policy change at different levels on international and domestic food prices and develop recommendations to enhance positive impacts on producers (increased productivity and incomes) and consumers (more stable food prices). Further, SI 1 scientists will work in each WHEAT SI to develop research prioritization recommendations, tools, and methods to ensure that WHEAT-generated innovations such as new germplasm, agronomic findings and practices together with its training program meet the needs of farmers and key stakeholders. For example, participation of social scientists in agronomic on-farm hub research for

SIs 2 and 3, or participatory varietal selection for SIs 4–7 and scenario analysis for SIs 3–6, will help ensure that the outputs from WHEAT are coherent and focused on the three core themes—poverty, food security and environmental sustainability.

Researchable issues

1. *Understanding the changing production conditions, trends in diversification and poverty dynamics, and implications for research and policy.* This will generate policy-relevant analysis to understand changes in irrigation, labor and resource-use patterns, shifts to rainfed conditions, and the underlying drivers of change that affect the future of wheat farming systems: wheat supply and price stability. One-shot studies are of limited relevance unless they can be positioned in a dynamic context that captures the key drivers of change, innovation, and livelihood diversification within representative farming systems. The wheat futures analysis will be conducted with IFPRI under CRP 2 using global partial or general equilibrium modeling frameworks. This will be part of the CRP 2 analysis of global policies for agriculture, strategic foresight and futures scenarios, investment strategies and priority setting, and analysis of the impacts of macro-economic and international trade on prices and food security. The micro studies (mainly funded from WHEAT) will generate and use panel data to analyze a range of issues in representative wheat systems, including crop productivity and resource-use patterns, gender effects, diagnosis and characterization of poverty traps/dynamics, and development pathways. This will be relevant to all SIs but linked with SIs 2–4 and SIs 6–7.
2. *How to leverage advances in social science to support technology generation and targeting to meet the needs of men and women farmers and challenges in priority farming systems.* This will include: the updating of wheat mega-environments; characterizing target groups/domains, spatial modeling and system analysis; topical research, such as economic feasibility for wheat in Africa; ex-ante impact analysis of CA options in wheat systems; enhancing durable resistance (wheat rust Ug99 and other major pests/diseases) underpinned by specialized (GIS) database; ex post analysis; and distributional and gender impacts of wheat interventions using gender-disaggregated surveys. This objective implies close collaboration with scientists from SIs 2–9 to help articulate the value proposition and to ensure that the outputs generated meet the needs of smallholder wheat farmers.
3. *Developing alternative institutional innovations that help improve access to wheat seed, inputs, and services.* This begins with: understanding the constraints and opportunities in order to revitalize seed systems; ways to accelerate replacement of dominant varieties; sustainable practices in irrigated systems; and enabling adoption of new cultivars and conservation agriculture in rainfed systems. Methods employed will include: characterization and analysis of wheat seed and complementary input systems (fertilizer, water); strategies and public-private partnerships for correcting market failures in delivering seed, equipment, other inputs and services; testing alternative models (e.g. using randomized experiments) for technology delivery, financing inputs, information, and advisory services; and policy options and regulatory frameworks to support pro-poor and gender-equitable input supply in the wheat systems without distorting incentives for input-use efficiency. This will be linked with SIs 2, 6, 7 and 8.

4. *Market innovations for reducing imperfections and volatility in wheat markets and developing efficient, quality-differentiated, and equitable value chains.* This will explore the extent of differentiation of wheat markets and the demand for specific end-user quality attributes and the role of nutritional benefits (micronutrients, bioavailability) and food safety in targeted value chains (linked with CRP 4). It will also examine the economic importance and effect of storage losses, poor grain quality, storage methods, unreliable supply, and high marketing costs on market demand and prices. The effect of production increases on domestic prices and the potential of food imports to smooth wheat consumption in low income developing countries will be evaluated with IFPRI under CRP2. The impact of poor market integration and trade policies on market risks for both producers and consumers, impact of price volatility on global food security, and the role of strategic reserves, trade and procurement policies for price stabilization will be assessed (link with CRP 2). This will also link with SI2 and SI4.
5. *Analysis of the impact of climate changes on different wheat farming systems and the extent of their vulnerability.* This will generate information on vulnerabilities, potential impacts, and economically viable adaptation/mitigation options for wheat farmers in different farming systems. It will also develop policy options for enhancing adaptation to and mitigation of climate change in wheat production environments. This will provide the economic analysis to help articulate the value proposition for SIs 3, 5 and 6 to respond to abiotic/biotic stresses associated with climate change. This objective will also link with CRP 7 on Climate Change and Agriculture for co-funding with CRP 3-Wheat.

Outputs

1. New knowledge, tools, and methods to better prioritize WHEAT research and better target interventions in wheat-based farming systems, for example:

- Guidelines for refining the WHEAT research priorities to effectively target poor farmers (especially women) and scale promising technologies.
- Gender analysis to evaluate the potential impact of new technologies on men and women, and to assess male/female preferences for various wheat traits—based on usage, knowledge, role in crop management, and the gendered impact of labor use and resulting decision-making power of research process and research outputs.
- Analysis of the impact of major wheat diseases on production and livelihoods, identification of practices that encourage disease incidence, and determination of the effectiveness of national policies and programs including extension and seed systems.
- Feasibility assessment of economic viability of wheat production in sub-Saharan Africa and elsewhere.
- Knowledge about the drivers of technology adoption and databases on the spatial and temporal diffusion of improved wheat varieties and conservation agriculture.
- Gender-differentiated knowledge on the impacts of interventions for poverty, livelihoods and sustainability in wheat systems. Improved capacity for targeting and scaling up new technologies and for analyzing their impacts.

- Recommendations about risks and opportunities that sustainably enhance wheat production and favorably impact on poverty alleviation
- Web-based tools including the wheat atlas and GIS made publicly available to aid technology targeting.

2. Institutional innovations for improving farmers' access to wheat technologies, input markets, and services, for example:

- Innovative institutional arrangements for seed production and dissemination using strategic public-private partnerships.
- Institutional arrangements for risk reduction, e.g. through innovative farmer-friendly insurance products.
- Strategies for enhancing public-private partnerships engaged in technology development and in supplying seed, equipment, and other inputs to smallholder farmers.
- Institutional innovations that contribute to pro-poor and gender-equitable delivery of seeds, fertilizer, information, credit, and other services.
- Alternative frameworks for regulating seed, including GM wheat, and policies that enhance access to seed, other inputs, and services.
- Improved capacity for analysis of seed systems and input value chains.

3. Market innovations that enable wheat value chains to meet consumer demand and provide stable prices more efficiently and equitably, for example:

- Strategic knowledge of wheat value chains, including the degree of differentiation and threats according to quality attributes preferred by importers, processors, and exporters as well as opportunities and threats for farmers.
- Information on the implications of market and quality differentiation for breeding and seed production.
- Innovations that create new market opportunities in quality-differentiated value chains for small-scale producers.
- Institutional innovations and policy options that reduce transaction costs, stabilize wheat prices, and improve small-scale farmers' market access and competitiveness.
- Improved capacity for analysis of wheat markets.

4. Evidence-based decision-making tools that help generate knowledge on socioeconomic dynamics and drivers of change in wheat systems and continually inform Output 1, for example:

- Baseline socioeconomic data including the role of women and men in wheat production systems, their access to innovations, intra-household dynamics, and livelihood strategies.
- Strategic knowledge on the regional and global wheat outlook and on investment options for ensuring regional and global food security.
- Strategic analysis and panel data to monitor socioeconomic and poverty dynamics, technological change, persistence of yield gaps, and drivers of change in representative farming systems.

- Policy options and instruments to promote income growth, diversification, and sustainable intensification of wheat systems.
- Pro-poor policy options and strategies that enhance foresight, stimulate technology adoption, and foster the inclusion of women and marginal farmers.
- Improved capacity for policy analysis in relation to changing wheat systems.

5. Assessments of the regional and global vulnerability of wheat systems to climate change and of options for adaptation and mitigation, for example:

- Regional and global diagnosis of the vulnerability of wheat systems and farming communities to climatic variability and ex-ante assessments of climate change impacts.
- Knowledge about strategies by which poor wheat farmers can adapt their production systems to heat, drought, land degradation, and water scarcity.
- Analysis of the costs and benefits of adaptation strategies and of the implications for research.
- Policy options for enhancing climate change adaptation and mitigation in wheat production environments.

SI 1 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: New knowledge, tools, and methods to better prioritize WHEAT research and better target interventions in wheat-based farming systems.	**1*, 3, 4, 5**			**17, 18**		**23, 27**
Output 2: Institutional innovations for improving farmers' access to wheat technologies, input markets, and services.	**2**	**7**	**10, 12**		**20**	
Output 3: Market innovations that enable wheat value chains to meet consumer demand and provide stable prices.		**9**	**11**	**15, 17**	**19, 22**	
Output 4: Decision making tools that help generate knowledge of socioeconomic dynamics and drivers of change in wheat systems.	**1, 4**	**8, 9**	**12, 13, 14**	**16**		**24, 25, 26**
Output 5: Assessment of vulnerability of wheat systems to climate change and options of adaptation.	**3**	**6**	**13**	**16**	**21**	

*Refer to numbered milestone descriptions in the text

SI 1 Key Milestones

1.	Ex-ante geospatial analysis of R&D opportunities completed for South Asia, CWANA and sub-Saharan Africa.	*2011*
2.	Household typologies developed for targeting innovations in at least three farming systems.	*2011*
3.	Wheat mega-environments updated with new data on climate, markets, and other factors.	*2011*
4.	Qualitative and quantitative tools for gender-responsive characterization of varietal traits and preferences by men and women developed and adapted.	*2011*
5.	Methods determined for establishing baselines to monitor adoption in SIs 2, 4 and 5.	*2011*
6.	Baseline data collected for characterization and adoption monitoring in three primary project intervention areas in SI 2, and for assessing past and on-going impacts for SIs 4 and 5.	*2012*
7.	Ex-ante analysis conducted on costs and benefits of durable resistance to disease and pests.	*2012*
8.	Ex-ante analysis of the profitability of conservation agriculture.	*2012*
9.	Gender analysis including the role of women and men in wheat production, processing, and marketing, as well as constraints and preferences in different socio-cultural systems relevant to the WHEAT agenda.	*2012*
10.	At least three new institutional innovations pilot tested for delivering inputs and technologies.	*2013*
11.	Wheat market and value-chain survey data analyzed and policy implications synthesized.	*2013*
12.	Policy briefs prepared on options for reducing transaction costs.	*2013*
13.	Feasibility of wheat production in sub-Saharan Africa assessed.	*2013*
14.	Publication prepared on wheat value chains and policy implications.	*2013*
15.	Analysis of coordination failures in wheat seed and output value chains completed for three countries.	*2014*
16.	Participatory variety selection and local adaptation of conservation agriculture analyzed.	*2014*
17.	Publication prepared on public and private sector roles in wheat input and output value chains.	*2014*

18.	Communicate results and R&D implications.	*2014*
19.	Publication prepared on poverty dynamics and drivers of socioeconomic change.	*2015*
20.	Research report on institutional innovations for equitable access to inputs and markets.	*2015*
21.	Publication on costs and benefits of climate change adaptation and research implications.	*2015*
22.	Policy brief on diversification in wheat systems and on the changing role of wheat in poverty reduction.	*2015*
23.	Improved methods developed for targeting, scaling, and evaluating technology impacts.	*2016*
24.	Publication on spatial and temporal flow of wheat technologies.	*2016*
25.	Economic, social, and environmental impacts of wheat innovations analyzed.	*2016*
26.	Wheat Futures to 2025 published.	*2016*
27.	Knowledge gaps and research needs identified for the second phase of WHEAT.	*2016*

Outcomes

- WHEAT and other stakeholders use SI 1 outputs to more effectively set priorities.
- Private sector and other partners adopt innovations to improve the delivery of seed, inputs, and financial services to farmers.
- Farmers and agribusinesses adopt market innovations to enhance the efficiency and equity of wheat value chains.
- Strategies that help stabilize food and feed prices are applied by WHEAT and other stakeholders.
- Governments and development partners using policy recommendations to enhance adaptation and reduce vulnerability to climatic impacts.
- Increased wheat production, resulting from adoption of institutional innovations for improving access to technologies and services to farmers.

Targets and impact estimates

The initiative will target wheat-based farming systems in low-income and low–middle income countries, particularly in South Asia, CWANA, sub-Saharan Africa, and Latin America.

Social scientists will work with wheat scientists to better understand the key constraints that limit farmers' adoption of new technologies and seizing of new market opportunities to improve their livelihoods. Better characterization of wheat farmers' needs and of the policy environment will result in better targeting of research outputs, thereby enhancing their impact on poverty, food security, and the sustainability of wheat systems. The major clients of this initiative will be collaborating wheat breeders and agronomists, policy analysts, governments, NGOs, and the private sector. The outcomes will lead progressively to reduced vulnerability, higher production, improved food security, increased marketed surpluses, higher incomes, more inclusive growth and gender equity, and improved agro-ecosystem health in wheat systems. The initiative will enhance the client orientation and impact of wheat R&D, helping development partners, governments and local actors to translate outcomes into concrete progress toward higher-level development goals. The role of the research partners will be to generate and deliver products of proven value and to promote their widespread adoption by clients. The diffusion and impact of innovations will be measured through rigorous ex-post evaluations.

Research and development partners

CIMMYT, ICARDA, IFPRI (Outputs 4 and 5); Michigan State University (Outputs 2 and 3); Cornell University (Output 3); UMB-Norway (Outputs 1, 4 and 5); University of Georgia (Output 1); regional and global policy research institutes, agricultural research institutes, universities, the private sector, and selected farmer organizations in more than 40 wheat-growing countries of Asia, Africa, and Latin America (Outputs 1–5).

What's new in this initiative?

- Integration of socioeconomic analysis with biophysical research priority setting, with renewed focus on participatory approaches and ex-ante analysis to determine outcomes and impacts of proposed interventions across multiple SIs.
- Clear focus on gender effects and poverty alleviation, with emphasis on the changing role of men and women in wheat-based agriculture; strategies for improving participation of women in technology development; and equitable access to information, markets, and other services.
- Increased interest in complex institutional innovations—for improving access to information, technologies, and markets as well as facilitating adaptation to and mitigation of climate change.
- Use of recent advances in geospatial analysis and wealth ranking tools for targeting the resource-poor and identifying specific biophysical and socioeconomic constraints to wheat production.
- Use of novel tools for market and value chain analysis—to quantify transaction costs, effect of grain quality on prices, market participation patterns, correlations between seed and output markets, and efficient strategies for linking farmers with markets.
- Improved documentation and 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.

SI 1 References

Byerlee, D. and Traxler, G. 1995. National and international wheat improvement research in the post-Green Revolution period: Evolution and impacts. *American Journal of Agricultural Economics* 77(2): 268–278.

Dixon, J., Braun, H-J., Kosina, P. and Crouch J. (eds) 2009. Wheat Facts and Futures. CIMMYT, Mexico.

Evenson, R.E and Gollin, D. (eds) 2003. Crop Variety Improvement and its Effect on Productivity: The Impact of International Agricultural Research. Wallingford, CABI.

Strategic Initiative 2. Sustainable wheat-based systems: Improving livelihoods while safeguarding the environment

Value proposition

Through equitable innovation systems with farmers and multiple institutions, enhance rural livelihoods by increasing total farm productivity and sustainability of both irrigated and rainfed wheat systems. By applying the principles of conservation agriculture, sequestering carbon in the soil and reducing soil erosion and degradation—while using labor and fuel more efficiently—for the benefit of poor smallholder farmers in Africa, Asia, and Latin America.

Estimated impact	2020	2030
Production increase per year	150,000 tons of wheat grain.	2.1 million tons of wheat grain.
Annual water savings	75 million cubic meters.	1.13 billion cubic meters.
Farmers who save 20% labor	500,000.	8 million.
Benefit to the poor	The target area includes over 100 million poor—with about 67 million in rural areas.	
Benefit to the environment	Reduced soil erosion and fuel use for tillage and pumping water as well as sequestration of carbon in soil organic matter.	
Annual value addition	USD 41.5 million.	USD 602.5 million.
Others	Reductions in labor requirements, which enable poor farmers to diversify into new enterprises.	

Justification

General background

Rural livelihoods and wheat production systems are threatened by ongoing soil and land degradation, water and labor scarcity, peak oil and phosphorus,[10] and further aggravated by the threat of climate change. Productivity decline from degradation of wheat production systems will contribute to diminished supplies and reduced global trade, which may lead to soaring prices with adverse effects on poor rural and urban consumers, and food security at the regional and global levels. Land degradation and irreversible loss of land productivity will also impose high costs on society in terms of future food security and flow of vital ecosystem services.

Soil erosion results in losses of potential productivity that are estimated to be equivalent to 20 million tons of grain per year worldwide. About 749 million hectares of agricultural land show moderate to severe water erosion; 81% of this land is in Africa, Asia, and Latin America (Oldeman 1994). The principal

[10] "Peak oil" and "peak phosphorus" are terms used to describe the moment when oil and phosphorus extraction reach their peak. There will still be reserves after these dates, but extraction will become more difficult and expensive.

causes of land degradation and erosion include: tillage, declining soil organic matter, and soil nutrient depletion (Lal 2009). Crop monoculture has led to increases in specific pests, diseases, weeds and, in some cases, prompting intensified use of pesticides.

Systems based on the three principles of conservation agriculture (CA)—minimum soil disturbance, adequate retention of crop residues on the soil surface, and crop rotation—remove or significantly reduce the three principal causes of soil and land degradation in conventional agricultural production: tillage, excessive organic matter removal, and monoculture. Such systems are the most sustainable options available today for field crop production. In addition to overcoming soil and land degradation, CA-based systems offer other major benefits as well. These include: soil water conservation, which reduces risk in rainfed environments; less labor and fuel use; increased soil organic matter, which leads to carbon sequestration and lower greenhouse gas emissions; greater availability of nutrients; and enhanced biological activity, both in the soil and aerial environment, that improves biological pest control. CA-based systems become more resilient as soil health improves, and crop yields will increase and risks will decrease, even in harsh environments (Erenstein et al. 2008).

Conservation agriculture is knowledge-based, involving changes in many components of the farming system. To develop, adapt, and disseminate such complex technology requires multiple agents with different skills and comparative advantages, who collaborate among themselves and with farmers in local innovation systems (or “hubs”) representing different agro-ecologies. In order for CA-based systems to remain productive, profitable, and sustainable they require sound crop management and practices, including proper selection of wheat (and other crop) varieties that are adapted to these systems.

Agricultural growth (in this case driven through increased productivity growth in wheat systems) provides for the most effective and efficient way to alleviate rural poverty—both directly in terms of farm income by making smallholders more efficient, and indirectly by providing cheaper food to the poor. Strategic Initiative 2 will contribute to sustainable intensification and productivity growth in wheat systems to reduce poverty and ensure that the natural resource base will remain an essential and viable building block for current and future wheat production and rural livelihoods. In addition, the initiative will pay particular attention to ensuring the inclusiveness of interventions and impacts, including positive changes in terms of gender equity, empowerment of women, and reaching the resource-poor, in both high-potential and less-favored wheat-producing areas that suffer from land degradation.

Lessons from past research

The overall strategy and focus of SI 2 has evolved from CIMMYT’s long history (over 30 years) of farming systems research for poverty reduction, food security, and increasing sustainability in cereal based systems. The applied research with sustainable systems, especially with those that today comprise conservation agriculture (CA), has demonstrated large-scale impacts in Latin America, South Asia (partially through the Rice-Wheat Consortium for South Asia) (Erenstein et al. 2008; Kassam et al. 2009);

more recently this research is being tested in southern and eastern Africa. Some of the principal lessons that have emerged from the extensive farming systems and poverty analysis work are:

1. Integrated interventions that could help lift large numbers of people out of poverty by addressing factors that prevent farmers from adopting technologies or investing in sustainable practices along the production-to-consumption chain (Barrett et al. 2002; Shiferaw et al. 2009).
2. Integrated interventions built upon specific successful innovations for improving the productivity of selected commodities—such as stress tolerant wheat and improved varieties of other crops within wheat systems—also exploit the positive interactions among different technology components (for example, rotation systems and intercropping for 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 have varying constraints and preferences for different technologies. Those implementing technology design and adaptation need to carefully understand these gender-specific roles and constraints and develop pro-poor technological and institutional innovations through participatory approaches that meet their needs and unlock local innovation (Quisumbing and Pandolfelli 2009; Meinzen-Dick et al. 2010).
4. An effective approach to promote investments in more sustainable practices by resource-poor farmers is to create economic incentives for adoption by building on high-return elements that raise productivity, create income opportunities, reduce vulnerability, and improve livelihoods (Barrett et al. 2002; Shiferaw et al. 2009). Environmental sustainability is not an end in itself; conservation programs that emphasized technical solutions and neglected the need to contribute to income growth and sustainable livelihoods have often failed. More complex and knowledge-intensive components that generate long-term economic and environmental benefits may require long-term local adaptation with strong external support both to strengthen local institutions and enable participation of the public and private sector service providers.

Some of the principal lessons that have emerged from this work are:

- CA is not a technology and is not transferable from one set of biophysical or socioeconomic conditions to another. Rather, the sustainable systems result from the adaptation of techniques and technologies used to apply the three basic principles of CA—minimum soil disturbance, surface residue cover, and crop rotation—to particular farm community circumstances. Disregard for this fundamental point has led to negative experiences with CA-based technologies in many places, where imported “CA packages” that have been applied without proper adaptation have failed. These failures have themselves led to the idea that CA-based systems have limited applicability in smallholder situations, as recently stated in a much publicized paper by Giller et al. 2009.
- 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 are considerable difficulties involved in the adaptation and application of CA-based agriculture for smallholder conditions, especially in regions of low crop productivity and relatively high climatic risk. However, research and participatory technology development show that these obstacles can be overcome, especially when it is understood that the alternative of continuing soil and land degradation is neither sustainable nor acceptable.
- The linear model of technology development and knowledge flow are not successful with more complex, multi-component technologies such as CA, which involve changes in many aspects of the farming system. For these technologies, multi-agent innovation systems focused on achieving change in target conditions are required.
- Natural drivers of change need to be felt by farmers. If they do not see the need for change, it will not happen. At the same time, farmers make both rational and emotional decisions, and both need to be part of the approach taken.
- Because adaptation of technologies to specific farmer circumstances is required for successful CA-based systems, work needs to be concentrated in particular areas rather than spread out over a wide geographical area. Also, the role of the farmer innovator in initiating change in farming communities is crucial to success.
- Policy and institutional innovations for the delivery of key productivity-enhancing technologies are critical in overcoming market imperfections that limit farmer technology adoption. They may include improved seeds and inputs (such as fertilizer), equipment (such as seed drills), access to credit and finance, and enhanced linkages with output markets for income generation. When supported with capacity-building in agribusiness and marketing skills, the establishment of producer cooperatives, farmer associations, marketing groups, self-help groups and other local collective-action institutions these activities play an important role in bridging the links between resource-poor farmers and input and output markets (Barrett et al. 2002; Shiferaw et al. 2009).

Methods for implementation of the Strategic Initiative

Technological and institutional innovations from different CGIAR centers and other partners will be integrated into options that allow sustainable intensification and productivity growth, with the aim of improving livelihoods and food security and thus reducing vulnerability in the wheat-based systems. Components of these systems will include: (1) stress-tolerant and better yielding varieties of wheat and legumes; and (2) efficient water and nutrient management practices that are affordable and scalable to reach large numbers of 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, so that they will be able to access seeds, fertilizer, other inputs and services in order to sell their surplus produce to raise incomes.

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 reduce risks—all while enhancing the sustainability of the system. The integrated technological and institutional innovators will progressively implement the principles of conservation agriculture and foster adoption of sustainable solutions at the farm and landscape level.

Activities of SI 2 will focus on pilot areas or “hubs” of coordinated activities in major smallholder wheat production systems. The central activity in the hub will be the catalysis and development of CA-based innovation systems suitable for the farming situation in the targeted community. Multi-season validation plots will be located in famers’ fields, and will be managed by the farmer. This will allow for demonstration, discussion, and refinement of the sustainable systems and will lead to farmer experimentation (the first stage of technology adoption) with the system. Once farmers have begun experimenting with CA systems and understand the principles and benefits of CA, local change agents will be encouraged and mentored in the process of facilitating farmer-to-farmer information and knowledge exchange: farmers believe other farmers, whereas they often have difficulty with messages from professional agriculturalists.

Undoubtedly technical problems, as well as opportunities for system enhancement, will become evident in the technology validation plots in farmers fields. These will provide the agenda for the applied research program 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 will be incorporated into the farmer-managed validation plots for evaluation by gender-differentiated groups in the community. As part of this process the research team will guide multiple learning activities to build knowledge about the processes of soil degradation and rehabilitation, crop and system productivity in the farming community and the innovation system.

Scaling the methodologies of CA-based system development and of the relevant technology components will be conducted by research and development partners linked to CRP 3. The hub activities and the functioning of the local innovation systems will provide the base for demonstration and capacity building, not just on technologies but also on the methodologies for participatory technology adaptation. However, the efficiency of scaling-out activities is increased by an understanding of both the biophysical aspects of technology benefits and requirements, and the socioeconomic possibilities of technology application and adaptation. To this effect, socioeconomic studies of the drivers of adoption will be conducted in the hubs, together with researcher-managed “long-term trials” to understand the effects of different technology options on soil and land degradation, soil quality, system productivity, and on weed, pest, and disease dynamics. These studies, together with both biophysical and economic system simulation modeling, will enhance the understanding of the benefits of the systems, permit greater security and targeting of scaling-out activities, and feed into the arena of policy debate. At the same time this work allows for the overall understanding of processes and the synthesis of these across farming systems and environments.

Why international agricultural research?

The international agricultural research centers have a critical role to play in achieving widespread adoption of ecologically sustainable, productive, and profitable farming systems. The centers can contribute primarily by developing, validating, and demonstrating the feasibility of such systems: by creating a better understanding of them; by facilitating their local adaption; and by enhancing national capacity to develop and manage local innovation systems, as distinct from a linear model of knowledge flow.

Researchable issues

- Innovative approaches for targeting the poor and vulnerable groups and scaling up promising innovations (including delivery of seed, other inputs and equipment) to wider target regions for rapid gains in productivity and livelihood improvement.
- Critical intervention points in the value chains of the principal enterprises involved in target cropping systems.
- Optimal enterprise mixes and technologies that benefit vulnerable groups (poor women, elders, etc.) by raising productivity and incomes, and analysis of tradeoffs (risk, profitability, sustainability) of various options using GIS data and crop and socioeconomic models.
- Important interactions between genotype and management with respect to CA-based systems: Are there important genotype x management interactions with respect to CA-based systems? (links to SI 4).
- Optimum levels of crop residues needed to reduce evaporation and increase soil organic matter content and soil biological activity, while freeing residues for other uses such as livestock feed.
- Interactions between the level of soil degradation, surface cover, and crop productivity in CA-based systems.
- Prospects for diversifying and intensifying rainfed systems (including the production of higher value forage) as a result of reduced labor requirements and less risk due to moisture conservation.
- Equipment for efficient seeding of wheat and different rotational crops into untilled soil covered with crop residues, under conditions of smallholder farmers with different sources of draft power, and including irrigated and other high-potential environments.
- Productive and economic fertilization strategies in CA-based systems and crop rotations.
- Management of nitrogen in CA-based systems to maximize nitrogen-use efficiency and minimize nitrate leaching and nitrous oxide emissions (links to SI 3).
- Use of increased biological activity in CA systems to reduce pesticide applications.
- Effects of CA systems on production risk, resource allocation, and variety adoption through impacts on weed, pest, and disease dynamics in different environments.
- Factors accounting for the benefits of crop rotation in CA-based systems and for enhanced biological nitrogen fixation (BNF) and soil phosphorus availability (links to SI 3).
- Productive and economic fertilization strategies in CA-based systems and crop rotations (links to SI 3).
- Effects of the adoption of conservation agriculture on downstream users.

- Acceptance and impacts of conservation agriculture in capital and labor-scarce production systems.
- Effects of reduced labor use on farm family livelihoods, enterprise selection and diversification.
- Role of government policies and institutional support in diffusion of CA-based systems, especially when externalities lead to sub-optimal farm-level investments.
- Relative balance between investments in developing CA-systems for favored and less favored wheat-producing areas in terms of direct and indirect poverty impacts.

SI 2 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: Locally adapted strategies link small producers with input, output and financial markets to enable adoption of improved wheat technologies.	1, 4*	2, 4	3, 4	4		
Output 2: Productivity-enhancing and risk-reducing technologies for regions with wheat-based systems lift large numbers of poor people out of poverty, including: • Alternative approaches for farmer land, labor, and financial resource allocation to crops (wheat, legumes, cash crops) and livestock that increase incomes and reduce risks (links to SI 1 and other CRPs). • Access to modern and stress-tolerant crop varieties (link to SI 4) and other CRP efforts.	1	2	3	7		
Output 3: Locally adapted sustainable systems based on the principles of CA increase productivity of land, labor and inputs, reduce risk (links to SI 1, CRPs 1, 5 and 7).	1	2	3, 5	5	5	5
Output 4: Local innovation systems, fostered in hub areas for the participatory development, scaled-out for sustainable, smallholder wheat-based systems (links to SI 1, CRPs 1 and 5).	1, 4	2, 4	3, 4	4		
Output 5: Wheat varieties selected that are well-adapted, both for CA and conventional tillage (links to SIs 4–5).	1, 2	2	3		8	
Output 6: Information and decision guides on residue value and demand requirements for maximizing system productivity in different environments (links to SI 10 and CRP 2).			3		8, 9	8
Output 7: Equipment for seeding different crops efficiently into untilled soil through surface residues under different soil and moisture conditions and with different sources of traction (links to CRP 1).	4	4	4, 5	4, 5	5	5

Output 8: Information and decision guides for fertilization in CA systems (links to SI 10).					**8, 9**	**8**
Output 9: Decision guides linked to weather forecasting services, supply farmers with timely information on optimum strategies for nitrogen fertilizer management, thus increasing fertilizer use efficiency and reducing risk (links to SI 3, SI 10, and CRP 1).				**6**	**8, 9**	**8**
Output 10: Innovative communication systems developed for conveying management recommendations to farmers via SMS (cell phone) (Links to SI 10).				**7**	**7, 8**	**7,8**
Output 11: Information on processes that account for the benefits of crop rotation in CA-based systems and that maximize the effects of biological nitrogen fixation and phosphorus availability (links to SI 3).	**1, 4**	**4**	**4**	**4**		
Output 12: Technological and institutional innovations enhance pro-poor relevance of interventions and social inclusiveness (links to SI 1 and 10).	**1**	**2**	**3**	**10**	**10**	**10**
Output 13: Policy options encourage adaptation and diffusion of CA-based systems for reducing vulnerability of livelihoods to biotic and abiotic stresses in wheat systems (links to SI 1).				**10**	**10**	**10**
Output 14: Information on management of weeds, pests and diseases in CA-based systems to minimize pesticide use (links to CRP 1).	**1**	**2**	**3**			
Output 15: Results from simulation models using field data to project the potential effects of adopting CA-based technologies at the district, watershed and regional levels (links to CRP 5).			**5**	**5, 6**	**5**	**5**

*Refer to numbered milestone descriptions in the text

SI 2 Key Milestones

1.	Strengthen and consolidate the five current hubs in Africa, Asia, and Latin America; identify sites for five new hubs and train all staff.	*2011*
2.	Research in five additional major wheat-producing systems is initiated and corresponding hubs are established. Breeding program for CA-based systems is established.	*2012*
3.	Six more hubs are initiated, giving 16 hubs in total. Constraints of system productivity documented (with SI 1) for each of the target production systems in the hubs, including an analysis of the value chains of the principal enterprises.	*2013*
4.	Initial CA systems developed with farmers, and options for improvement, intensification and diversification incorporated into participatory on-farm research programs (one year after hub establishment).	*2011-14*
5.	Farmer experiments with CA-based technologies within the hubs monitored, and relevant technologies and modifications incorporated into local systems.	*2013-16*
6.	Crop/soil simulation models validated under CA across a minimum of eight hubs.	*2014*
7.	Strategies for enhancing farmers' access to information and knowledge (including the use of technology and market information centers via cell phone and the internet) developed and tested in at least six hubs (with SI 10).	*2014*
8.	Decision guides developed (with SI 10) for scaling out profitable and sustainable production systems in at least eight hubs and used by at least 500 farmers or extension agents in each hub.	*2015*
9.	Decision guides developed (with SI 10) for scaling out profitable and sustainable production systems in at least eight hubs and used by at least 500 farmers or extension agents in each hub.	*2015*
10.	Institutionalization of the innovation systems. Partners scale out successful CA systems through the facilitation of farmer-to-farmer exchange.	*2014-16*

Outcomes

- Policy makers, researchers, change agents, and farmers understand the feasibility and importance of applying the principles of conservation agriculture.
- Farmers in developing countries equitably enhance their food security and livelihoods while minimizing the unsustainable effects of their farm management on the soil and environment.
- 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 to increase incomes.

- Researchers and change agents in developing countries are better equipped to catalyze and participate in equitable, pro-poor, multi-agent innovation systems and to facilitate information and knowledge flow between farmers.

Targets and impact estimates

The initiative will target five irrigated and seven rainfed wheat production systems in the developing world as shown in the following table. There will be at least one hub in each system, with more than one hub in systems that cover larger areas and have more diverse conditions. Within each hub, major activities will be concentrated in a limited number of communities to permit sufficient support for initial adopters and farmers hosting project activities.

This SI will develop improved management options to make wheat-based systems more profitable and sustainable. These will be applicable on at least 74 million hectares of wheat (half in irrigated and half in rainfed/dryland farming systems). Adoption will be demonstrated on 500,000 farms within 10 years. Benefits will include increases of at least 10% in the yields of irrigated wheat on 8 million farms in 20 years. Adopting farmers will also use 20% less fuel and labor; 1.5 million of them will also reduce by 15% the amount of irrigation water they use. In rainfed wheat areas, average wheat yields will increase by 20% on at least 3 million farms by 2030. While increasing yields and input-use efficiency and reducing production risk, farmers will also improve soil quality, reduce soil erosion and foster carbon sequestration in the soil. The total value accruing to these benefits is estimated at USD 44 million by 2020 and over USD 680 million by 2030.

Region	System	
Irrigated systems		**No. of hubs**
South Asia	Rice-wheat system	4
South Asia	Dryland irrigated (wheat-cotton)	1
Central Asia	Dryland irrigated	1
East Asia (China)	Rice-wheat	1
Mexico	Irrigated	1
Total Irrigated		**8**
Dryland/rainfed systems		
South Asia	Rainfed mixed	2
West Asia	Small-scale cereal livestock	1
West Asia	Rainfed mixed	1
East Asia (China)	Temperate mixed/dryland	1
North Africa	Small-scale cereal livestock	1
East Africa	Highland temperate mixed	1
Mexico	High-altitude mixed	1
Total rainfed/dryland		**8**

Gender

CA-based systems need to be adapted to local conditions and farmer circumstances. In this participatory process the views of different sectors of the farming community will be taken into account, especially the views of women. In ongoing research projects that form the basis for this SI, we follow the three principal guidelines for practitioners of agricultural research outlined in the World Bank/FAO/IFAD Gender in Agriculture Sourcebook (World Bank 2009):

- Identify research issues using participatory diagnosis involving both women and men farmers.
- Encourage producer men and women to provide information on local, indigenous, and traditional ways of dealing with the identified research issues.
- Ensure diverse gender perspectives through in-depth understanding of the diverse roles, choices and preferences of women and men in wheat systems.

This incorporation of gender-differentiated information into the research process will tend to ensure that the results of the SI are not biased against women, young adults, or elders. This will also be informed by the broader gender strategy and SI 1 research for WHEAT described earlier.

By reducing labor demands, CA-based systems may have differential gender benefits. Initially, the reduction in tillage may benefit men more than women, as men are more involved in tillage in some cultures. However, as weed populations decline, women and children will benefit from reductions in labor requirements. In Latin America CA-based systems have been shown to increase school attendance, whereas in sub-Saharan Africa they have particular advantages for HIV-affected households. This SI will track gender-specific changes and impacts with the aim of enhancing inclusiveness, social equity and positive gender impacts. Furthermore, the incorporation of crop rotation and diversification as one of the basic tenets of CA-based systems will provide an opportunity for the incorporation of other food crops into the system, which will help meet the choices or social roles of women in enhancing nutritional security of the family and children.

One of the components of CA-based systems that will be followed in SI 2 is the incorporation of agro-forestry species into the farming system. This will enhance the supply of firewood, providing a ready source of fuel, and thereby benefitting women and children, specifically in many African cultures where women and children are generally responsible for firewood collection.

Research and development partners

The innovation systems in the hubs will necessarily involve multiple agents. Because of the participatory nature of this work it is impossible to differentiate between research and development partners; all are involved to some degree in both research and development. Farmers will be principal partners in the innovations systems together with:

- International centers including CIMMYT, ICARDA, ILRI, and IRRI.
- National program researchers and change agents from Afghanistan, Algeria, Bangladesh, China, Ethiopia, India, Iran, Kazakhstan, Kenya, Kyrgyzstan, Mexico, Morocco, Nepal, Pakistan, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan, and Uzbekistan.
- Advanced research institutes, including: Cornell University, USA; Stanford University, USA; Oklahoma State University, USA; CSIRO, Australia; University of Washington, USA; CIRAD, France; and EMBRAPA, Brazil.
- National and international NGOs, including CARE International, CARITAS, CRS, Concern Universal, Save the Children, and World Vision.
- FAO, the African Conservation Tillage Network (ACT), the Professional Alliance for Conservation Agriculture (PACA) in India, and ASOSID in Mexico.
- Machinery manufacturers, input suppliers, credit agencies, service providers, seed companies, regulatory agencies, seed traders associations, and grain dealers.
- In East Africa, specifically, SI 2 will work closely with the East Africa Productivity Program—Wheat of ASARECA.

What's new in this initiative?

- The initiative will fundamentally change tillage-based agriculture that is widely practiced in the developing world.
- The initiative will work through local innovation systems in representative environments to develop sustainable systems based on the principles of conservation agriculture and will strengthen local capacity.
- Varieties that are adapted to both CA-based systems and conventionally tilled systems will be selected.
- NARSs, NGOs, ARIs, grain purchasers, credit and input suppliers, machinery manufacturers, and others will be included in the innovation systems.
- The initiative will focus on innovations to ensure equitable, pro-poor access and impact from the onset—with particular attention to include smallholders, women, and the poor.

SI 2 References

Barrett, C. B., Lynam, J., Place, F., Reardon, T. and Aboud, A. A. 2002. Towards improved natural resource management in African agriculture. In: Barrett, C., Place, F. and Aboud, A. (eds.), Natural Resource Management in African Agriculture. Undersigning and Improving Current Practices. CAB Publishing, 287–296.

Erenstein, O., Sayre, K., Wall, P., Dixon, J. and Hellin, J. 2008. Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis W., Watson, A. and Sombatpanit, S. (eds), No-till Farming Systems. Bangkok: World Association of Soil and Water Conservation (WASWC), 253–278.

Giller, K.E., Witter, E., Corbeels, M. and Tittonell. P. 2009. Conservation agriculture and smallholder farming in Africa: The heretic's view. *Field Crops Research*, doi 10.1016/j.fcr.2009.06.017

Kassam, K., Friedrich, T., Shaxson, F. and Pretty, J. 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability* 7(4): 292–320.

Lal, R. 2009. Editorial: Soils and world food security. *Soil and Tillage Research*, 102: 1–4.

Meinzen-Dick, R., Quisumbing, A., Behrman, J., Biermayr-Jenzano, P., Wilde, V., Noordeloos, M., Ragasa, C. and Beintema, N. 2010. Engendering Agricultural Research. IFPRI Discussion Paper 00973 May 2010, Washington DC.

Oldeman, L.R. 1994. The global extent of soil degradation. In: Greenland, D.J. and Szabolcs, I. (eds). Soil Resilience and Sustainable Land Use. CAB International, Wallingford, 99–118.

Quisumbing, A. and Pandolfelli, L. 2009. Promising approaches to address the needs of poor female farmers: Resources, constraints, and interventions. *World Development* (in press)

Shiferaw, B., Okello, J. and Reddy, V.R 2009. Adoption and adaptation of natural resource management innovations in smallholder agriculture: Reflections on key lessons and best practices. *Environment, Development and Sustainability* 11: 601–619.

World Bank 2009. Gender in Agriculture Sourcebook. The World Bank, Food and Agriculture Organization, and International Fund for Agricultural Development: Washington, D.C.

Strategic Initiative 3. Nutrient- and water-use efficiency

Value proposition

Develop and disseminate novel methods, decision guides, information and wheat germplasm that allow smallholder irrigated wheat farmers to produce their wheat crop with less fertilizer and water, and smallholder wheat producers in non-irrigated (rainfed) areas to increase crop yields and reduce their risk of economic losses.

Estimated impact	2020	2030
Reduction in fertilizer use without reducing yield	21,780 tons of nutrients saved.	217,800 tons of nutrients saved.
Water saved for other uses	625 million cubic meters of water saved.	2.5 billion cubic meters of water saved.
Increase in grain production	375,000 additional tons of grain produced (on average) per year in dryland wheat areas.	1,875,000 additional tons of grain produced (on average) per year in dryland wheat areas.
Benefit to the poor	Enhanced water-use efficiency in dryland areas reduces vulnerability to crop loss from drought; greater profitability of wheat systems.	
Benefit to the environment	Reductions in N_2O emissions, nitrate leaching, phosphorus losses to surface water, and fuel used for pumping water.	
Annual value addition (grain and nutrient saved)	USD 109 million	USD 643 million
Others	Agronomic capacity of national programs strengthened. Formation of an international network of crop agronomists.	

Justification

General background

Inefficient management of water (H_2O), nitrogen (N) and phosphorus (P) threatens the environment and increases crop production costs, thereby reducing profitability and increasing the risk associated with crop production. Methods to increase the use efficiency of water and nutrients need to be incorporated into sustainable systems. In the short term, advances can be made by improving efficiency in current, often unsustainable systems, but our vision must remain on long-term sustainability. Poor water management leads to large-scale soil erosion and salinization. Poor nitrogen management leads to excessive leaching of nitrate into groundwater and the volatilization of nitrous oxide, a greenhouse gas with a global warming potential approximately 300 times greater than that of carbon dioxide. Poor phosphorus management can lead to severe problems of eutrophication, where dissolved phosphates stimulate excessive growth of aquatic plants that choke waterways and deplete the water of oxygen, to the detriment of other life forms.

Wheat is the crop to which most nitrogen fertilizer is applied globally—19% of all N fertilizer. Of the 90.9 million tons of nitrogen fertilizer used globally, 70% is applied in the developing world, most of it in only three countries: China, India, and Pakistan. Nitrogen-use efficiency (NUE = kg grain / kg N applied) in developing countries is commonly only around 33%, but it is economically feasible to increase this level to 65%. In rainfed areas NUE is intricately linked to rainfall and decision guides linked to weather information for farmers are critical to increasing efficiency. Phosphorus reserves for fertilizer are not unlimited, and peak phosphorus production is likely to be reached as early as 2030, after which supplies will be much more difficult and expensive to obtain (van Kauwenbergh et al. 2010).

Competition for water among urban users, industry, and agriculture will lead to less water available for irrigation and increase the need to produce “more crop per drop”. Similarly, in rainfed (non-irrigated) agriculture the efficient use of rainfall and of supplementary irrigation will be the key to agricultural production and adaptation to climate change.

To meet future wheat demand sustainably, farmers will need to produce more while making dramatically more efficient use of water, nitrogen, and phosphorus. This SI will develop tools and methodologies that increase input-use efficiency, and incorporate them into functional, sustainable farming systems to help close the gap between actual and economically realistic yields. This SI will also, closely linked with SI 4 and 9, focus on identifying wheat accessions for use in breeding programs, to exploit the genetic differences among wheat cultivars for acquisition of soil mineral nitrogen and uptake and utilization of applied fertilizer nitrogen (Foulkes et al. 1998).

While present recommendations for economic phosphorus fertilizer applications are generally good, results with nitrogen recommendations are generally not as precise. Furthermore, it is difficult for smallholder farmers, who may own several small plots with different field histories, to afford and obtain soil analyses. In most cases laboratory capacity is insufficient to analyze all the samples if smallholder farmers were to request the analyses.

Researchers have been working in recent years with different methods to directly assess crop nutrient requirements. Their methods range from leaf color (in rice) to chlorophyll sensors and remote-sensing devices—including those installed in satellites and hand-held devices—to predict nitrogen and phosphorus responses. Results to date have been especially promising using remote sensors for nitrogen response predictions in both irrigated and (especially when linked to weather data) rainfed wheat crops, and studies are underway to adapt the results to other crops. Technically, it is feasible that other nutrient deficiencies and responses may be identified by leaf reflectance using different wavelengths.

Techniques for nutrient application can also increase nutrient-use efficiency and will be explored in SI 3. While phosphorus fertilizer use efficiency may be very high when considered over a number of years (Syers et al. 2008), in the year of application the amount of the applied phosphorus taken up by the crop may be 16% (Mosali et al. 2006) or lower. For smallholder farmers the short-term benefits of fertilizer application are all important and longer-term benefits discounted heavily. Therefore, options to increase the short-term response to phosphorus fertilizer will be explored, including formulations, mycorrhizal inoculation, and fertilizer placement.

As for most applied inputs, the "Law of Diminishing Returns" applies to irrigation water—large increases in efficiency can be achieved by applying less than optimum amounts of water at critical times. This also holds for rainfed areas where some supplementary irrigation can be applied. Very large increases in yield and very efficient water use can be achieved with tactically applied supplementary irrigation. Varieties of wheat differ in their response to reduced water and so genotype x management interactions will also be explored with respect to supplementary irrigation. Modeling will be an integral part of this research component and will be carried out through linkage with CRP 7.

In the past, smallholder farmers tended to receive technical information from sporadic visits from extension personnel and/or commercial sales people. Recommendations on farmer practices and input use under this model needed to be general in nature, as it was impossible to tailor the recommendations to the multitude of different field and weather conditions. The explosion in information and communication technology and the widespread insertion of cell phone networks into rural communities now offer the possibility of far more precise and time-sensitive information flow, but new research and simulation modeling is also required to produce the right information for correct, precise, and massive diffusion.

Advances in computing, modeling, weather forecasting, remote sensing, and communications also offer opportunities for small-scale farmers to access precision technologies. This will require establishing new and dynamic partnerships that cannot be foreseen at the moment. Some outputs, particularly those developed with national agricultural research and extension system scientists, may have immediate applicability in farmers' fields. Others will need to be incorporated into integrative, farming system approaches. Delivery of the more immediate products will be through the national agricultural research and extension system. These and other outputs from the SI will feed into the WHEAT Sustainable Systems SI 2, CRPs 1 and 7, and similar initiatives.

Research focus of SI 3

The focus of this SI will be on increasing the efficiency of nitrogen, phosphorus and water use through both, precision agriculture and improved wheat germplasm. Other factors that limit input use efficiency, like pests and diseases, micronutrients etc. will be addressed through linkages with SI 4 and 5, since where any of these factors limit yield they also limit the efficiency of use of N, P and H_2O. Therefore diagnosis of field problems and the application of solutions to these becomes an integral part of the SI.

With respect to diagnosis of N, P, and H_2O status as well as to the prediction of responses to applied inputs, present techniques will be tested and research on possible new technology and technology applications monitored and incorporated into the research program. It is likely that as ICT advances, new technologies will offer further possibilities for increasing the efficiency of diagnosing plant nutrient and water status and predicting responses to applied inputs. Once techniques are validated, ex-ante analysis of the potential cost of the techniques compared with the potential economic benefits will be conducted, algorithms to relate measured data to crop response developed, and on-farm participatory research conducted to validate the technology. Once the feasibility of the techniques is validated, training in the management and use of the techniques will be an important component of the up-scaling and out-scaling of SI outputs.

Crop and soil management methods have large influences on input-use efficiency. Research will be conducted on the methods to enhance the effects of sustainable systems, based on: the principles of conservation agriculture (CA, cf. SI 2) in relation to phosphorus-use efficiency; soil erosion (one of the major causes of nutrient losses); soil structure, porosity and root exploration; and the efficient management of nitrogen fertilizer in CA-based systems to increase NUE and reduce nitrous oxide emissions.[11] The effects of different species in crop rotations on nitrogen and phosphorus fertility will be evaluated and productive options incorporated into the farming systems work of SI 2. This work will be done in conjunction with other studies on restricting drainage losses of nitrate through nitrogen fertilizer management and through the selection of wheat varieties whose root exudates inhibit nitrification.

Why international agricultural research?

International agricultural research has an important role to play in developing public goods that lead to environmental and social benefits not generally prioritized by the private sector. In partnership with advanced research institutes, national agricultural research and extension systems, and the private sector, international centers can help test, adapt, and develop new tools and technologies that increase the precision and efficiency of smallholder wheat production. In SI 3, linked with SI 9, genetic resources are screened for new sources of nitrogen, phosphorus, and other nutrient efficiency genes. This research will be conducted in conjunction with multiple partners, especially advanced research institutes (e.g., BBSRC-UK, INRA-France) and the national agricultural research and extension systems of Brazil, China, Egypt, India, Iran, Morocco, Pakistan, Syria and Turkey. Once nutrient use efficient lines have been identified, these traits will be incorporated into a breeding program that addresses these traits in conjunction with the ongoing international wheat-breeding effort.

[11] An example of the importance of monitoring research into new technologies is that the "Normalized Difference Vegetation Index" (NDVI) is currently being successfully used in some areas to predict optimum nitrogen application amounts. This technology was developed to measure season length, based on the start of season greening and the end of season plant senescence, using satellite sensors. Later it was adapted to measure leaf area index and then relative nitrogen content. The technology, especially using other wavelengths, has further potential for measuring or diagnosing other conditions that affect leaf color and reflectance.

Researchable issues

How efficiently nitrogen, phosphorus or water are used in wheat grain production depends on making the input available in the soil, reducing losses from the soil, and ensuring the crop can access the input and use it efficiently to produce grain. Each process may be modified to increase input-use efficiency while reducing damage to the environment. Specific researchable issues include the following:

- Improving fertilizer use efficiency by optimizing the application rate (taking into account spatial variability and climate, including weather forecasts), timing, placement, and product formulation used. These will include remote sensing and satellite imagery.
- Reduce N losses through biological nitrification inhibition (BNI); BNI-controlling genes on *Leymus*-wheat disomic chromosome addition lines are transferred into elite wheat lines (linked to SI 9).
- Development of screening and selection methodologies for selection of lines from segregating populations with increased efficiency in uptake of nitrogen and phosphorus and for response to limited irrigation (linked to SI 4 and 6).
- Methods, techniques, and technologies to reduce N losses through drainage by inhibiting nitrification, using nitrapyrin or similar products, or genetically through root exudates using genes from *Leymus* spp. (linked to SI 9).
- Reducing de-nitrification and volatilization losses; soil management to reduce water saturation and anaerobic soil conditions; and adequate fertilizer formulation/placement.
- Phosphorus availability through soil organic matter and root exudates, both from wheat varieties and other crops in the rotation.
- Tools and decision guides for determining the timing and amount of irrigation water, including supplementary irrigation, and nitrogen applications.

SI 3 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: Methods and decision guides on nitrogen use efficiency in China, India, and Pakistan.	**1***	**2**		**4, 5**		**8**
Output 2: Support systems through cell-phone-based information.					**6**	
Output 3: Decision guides on reducing leaching and N losses.	**1**	**2**		**4, 5**		**8**
Output 4: Wheat lines with nitrogen and phosphorus-use efficiency.				**3**		**8**
Output 5: Methods to increase phosphorus-use efficiency.					**7**	
Output 6: Methods to increase irrigation-use efficiency.					**7**	**9**
Output 7: Guides on rainfall-use efficiency.					**7**	**9**
Output 8: Information bulletins for extension agents and farmers.				**5**		**9**

*Refer to numbered milestone descriptions in the text

SI 3 Key Milestones

Milestones are defined on the basis of current knowledge and tools. However, innovation and the incorporation of new technology may make some of these milestones obsolete before they happen, in which case they would be replaced by even more effective milestones, outputs, and outcomes.

1.	A **normalized difference vegetation index** (NDVI) sensor for determining topdressing nitrogen requirements validated under irrigated wheat conditions in China, India, and Pakistan.	*2011*
2.	Nitrogen-use efficiency increases resulting from the use of pocket NDVI sensors in China, South and West Asia, North Africa, and Mexico.	*2012*
3.	Genes controlling Biological Nitrification Inhibition transferred from Leymus into elite lines available for use by partners and in SI4.	*2014*
4.	At least 10,000 smallholder wheat farmers increase their nitrogen fertilizer-use efficiency by 20% or more.	*2014*
5.	Decision aids developed (with SI 10) through field research and simulation modeling (with CRP 7) to manage nitrogen more efficiently in rainfed wheat production systems, allowing farmers to harvest better yields in favorable years and reduce the risk associated with fertilizer use.	*2014*
6.	Rainfed wheat farmers in pilot areas in 4 countries obtain information such as weather forecasts and recommendations for nitrogen use through cell phone systems (with SI 10).	*2015*
7.	Methods developed to easily assess water-use efficiency in at least four smallholder rainfed wheat production environments and used to demonstrate more efficient management practices.	*2015*
8.	At least 10,000 smallholder wheat producers in China, India, and Pakistan increase their nitrogen-use efficiency by around 50%.	*2016*
9.	At least 10,000 smallholder irrigated wheat producers in South and East Asia reduce the amount of water applied to wheat by at least 25% without reducing crop yields.	*2016*

Outcomes

- Smallholder farmers in China, India, and Pakistan have access to methods and technologies with the potential to produce up to 50% more grain per kilo of nitrogen and phosphorus fertilizer applied.
- Farming systems made available with the capacity to reduce nitrogen losses by leaching and volatilization by at least 20%.
- Smallholder wheat producers in Asia and North Africa provided with technologies to use at least 25% less water to produce comparable or higher wheat yields than those presently obtained.

- Small-scale, rainfed wheat farmers gain access to farming systems which potentially produce at least 14 kg grain per mm of soil water, after discounting evaporation.

Targets and impact estimates

Both irrigated and rainfed wheat production will be targeted in this SI. Work on increasing the efficiency of applied nitrogen will focus on those countries that apply the most N fertilizer to wheat (China, India, Pakistan), together with research on improving irrigation efficiency, especially in the rice-wheat and maize-wheat areas of South and East Asia; the cotton-wheat system in Central Asia, Egypt, India and Pakistan; and the irrigated wheat area in Egypt and Mexico. Research on decision aids for tactical nitrogen applications aided by weather forecasting will focus on the major rainfed smallholder wheat systems—the rainfed mixed systems of South Asia, the temperate mixed/dryland system of China, the cereal-livestock system of West Asia and North Africa, the rainfed mixed system of Central and West Asia, the highland temperate mixed system of East Africa, and the highland temperate system of Latin America. Phosphorus efficiency research will be conducted in South and East Asia, West Asia, and Latin America, but will extend to all regional as promising result become available.

We believe that by 2020, at least 300,000 farmers in South and East Asia will use 33% less nitrogen fertilizer than they would otherwise have used and by 2030 that number will have risen to three million. Likewise, methods to increase the use efficiency of irrigation water by 25% or more will be adopted by at least 500,000 farmers in 2020 and by two million farmers in 2030. If subsidies on irrigation water were removed in South Asia, these numbers would increase markedly. In rainfed wheat areas, the risk of dry weather limits farmers' fertilizer use. Through information systems based on fertilizer response data and weather forecasts, farmers in such areas will be able to reduce the risks of nitrogen application, take better advantage of good seasons, and reduce their losses in poor seasons. As a result, in 2020, one million smallholder rainfed wheat producers will produce an average of 25% more yield across all seasons. By 2030, this number could rise to at least five million. The total annual value of these benefits is estimated at USD 109 million in 2020 and nearly USD 643 million by 2030.

Phosphorus fertilizer is generally applied at or before seeding and in lower quantities than nitrogen fertilizer. For this reason, increases in solid fertilizer-use efficiency are not likely to be as great as those in nitrogen fertilizer-use efficiency. However, improvements in soil phosphorus availability through system management will lift the yields of at least 100,000 farmers by 2020 and of one million farmers by 2030. Breakthroughs in phosphorus formulations and application methods could provide far greater benefits for many more farmers.

Research and development partners

Collaboration with a wide range of national agricultural research and extension systems and advanced research institutes is foreseen. The following institutions will be invited to join the initiative, but many others will participate over time as new technology options are developed. Major partners will include the national research programs of China, Mexico, and the South Asian and CWANA countries, along with

IRRI and ICARDA. The following partners are also likely to form part of this initiative: BBSRC-UK and INRA-France (screening and selection of wheat accessions with enhanced NUE); Oklahoma State University, USA (nitrogen- and phosphorus-use efficiency); Stanford University, USA (simulation modeling and remote sensing); CSIRO, Australia (water-use efficiency, phosphorus-efficient varieties, crop modeling, biological nitrification inhibition); EMBRAPA, Brazil (biological nitrogen fixation); Murdoch University, Australia (biological nitrogen fixation); and Ohio State University, USA. Cell phone manufacturers and providers will also be involved in the development of community information systems.

Our main development partners will be the national agricultural research and extension systems of China, India, Mexico, and Pakistan. As the initiative progresses additional partner countries will include Algeria, Afghanistan, Bangladesh, Ethiopia, Egypt, Iran, Kazakhstan, Kyrgyzstan, Morocco, Nepal, Syria, Tajikistan, Tunisia, Turkey, Turkmenistan, and Uzbekistan. Other important development partners will be local and international non-governmental organizations, industrialized country development agencies, and cell phone service providers.

Other issues

Gender

It is difficult to envisage that the technologies researched in SI 3 will have differential gender effects or benefits. However, this will be continually checked during the participatory on-farm validation phase of the technology development (with SI 1), using the principal guidelines for practitioners of agricultural research outlined in the World Bank/FAO/IFAD Gender in Agriculture Sourcebook (World Bank 2009), as follows:

- Identify research issues using participatory diagnosis involving both women and men farmers.
- Encourage producer men and women to provide information on local, indigenous, and traditional ways of dealing with the identified research issues.
- Ensure diverse gender perspectives by suggesting that initial “data collection” is done in separate groups of women and men.

It is probable that there will, however, be generational effects on the appeal of the technologies, especially when these use up-to-date information and communication technology, with greater interest and uptake likely among young adults. There are also likely positive inter-generational effects with the development of components for sustainable systems that reduce soil and land degradation and result in reduced greenhouse gas emissions.

Dissemination pathways

Dissemination of information and research results will partially be effected through the publication of decision guides for researchers, change agents, and innovative farmers. This will be supported by focused capacity-building efforts for researchers in the target systems in close coordination with SI 10. At the same time, the technologies, techniques, and decision guides from SI 3 will feed directly into the hub activities in SI 2, where they will be incorporated into the farming system research and become one component of the dissemination to development partners, researchers and farmers in that SI.

What's new in this initiative?

- The science behind NDVI sensors for nitrogen fertilizer dosing is established, but the use of recently released, simple, affordable, and user-friendly sensors needs to be validated. Algorithms for calculating optimum nitrogen applications in different systems and environments need to be developed.
- Improved weather forecasting, fertilizer response data, and crop modeling are combined to produce decision guides that can be transmitted rapidly and efficiently by SMS messages to thousands of farmers (with SI 10).
- An integrated crop, soil, and fertilizer management approach to enhance short-term responses to nitrogen and phosphorus fertilizer.
- Selection of wheat varieties for nitrogen and phosphorus uptake efficiency and biological nitrification inhibition (with SI 9).

SI 3 References

Foulkes, M. J. , R. Sylvester-Bradley and R. K. Scott. 1998. Evidence for differences between winter wheat cultivars in acquisition of soil mineral nitrogen and uptake and utilization of applied fertilizer nitrogen Journal of Agricultural Science, Cambridge (1998), 130, 29±44.

Mosali, J., Girma, K., Teal, R.K., Freeman, K.W., Martin, K.L., Lawles, J.W. and Raun, W.R. 2006. Effect of foliar application of phosphorus on winter wheat grain yield, phosphorus uptake and use efficiency. *J. Plant Nutr.* 29: 2147–2163

Syers, J.K., Johnson, A.E. and Curtin, D. 2008. Efficiency of soil and fertilizer phosphorus use. Reconciling changing concepts of soil phosphorus behavior with agronomic information. FAO Fertilizer and Plant Nutrition Bulletin No. 18. FAO, Rome, Italy. 108 pp.

Van Kauwenbergh, S. J. 2010. World Phosphate Rock Reserves and Resources. IFDC, Alabama, USA.

World Bank 2009. Gender in Agriculture Sourcebook. The World Bank, Food and Agriculture Organization and International Fund for Agricultural Development: Washington, D.C.

Strategic Initiative 4. Productive wheat varieties

Value proposition

Maintain a 0.9% per annum growth rate in wheat productivity by breeding robust, farmer-preferred wheat varieties through a strengthened international testing network that includes CIMMYT, ICARDA, national programs, agricultural research institutes, and the private sector, and that contributes to affordable food security for two billion disadvantaged wheat consumers in Asia, Africa, and Latin America.

Estimated impact	2020	2030
Annual production increase	2.1 million additional tons of wheat grain per annum.	2.5 million additional tons of wheat grain per annum.
Benefit to the poor	Sustained growth in wheat productivity through new higher-yielding varieties resistant/tolerant to biotic and abiotic stresses, and with appropriate end-use quality, together with rational use of agrochemicals, will contribute to increasing the profit margin for wheat producers. Resource-poor farmers will be less vulnerable to crop losses from diseases, pests and environmental stresses. Enhanced production will help maintain wheat prices at an affordable level for the urban poor.	
Benefit to the environment	Reduced pressure to bring natural ecosystems under cultivation; water- and nutrient-use efficiency increased in existing wheat systems, helping to stabilize the natural resource base. Optimizing and, in the long-term, minimizing pesticide use.	
Annual value addition	USD 462 million.	USD 610 million.
Other	Strengthening of national agricultural research programs through the provision of new diversity for various traits packaged in diverse, high-yielding germplasm will contribute to the long-term sustainability of wheat improvement research and the development of input-efficient, robust wheat varieties that meet farmer and consumer demands.	

Justification

Irrigated areas with intensive, highly-productive farming systems are the breadbaskets of major wheat-producing countries, including Afghanistan, Bangladesh, China, Egypt, India, Iran, Iraq, Kyrgyzstan, Mexico, Pakistan, Sudan, Syria, Turkey, Turkmenistan, and Uzbekistan. These countries grow more than 45 million hectares of spring wheat and another 15 million hectares of facultative and winter wheats.[12] These irrigated farming systems, which are central to reducing poverty in Africa and Asia, face serious problems, including the over-exploitation of water and soils, inefficient use of chemical inputs, emerging or worsening disease and pest problems, and high temperatures. Crop improvement focuses on overcoming these limitations by developing new varieties that have built-in tolerance/resistance to diseases, pests, drought, heat, salt, and other constraints, thus ensuring that the key agricultural areas will remain productive and ecologically sound into the future. New wheat varieties have contributed about 0.9% annually to productivity growth over the past decade.

[12] Winter and facultative wheats are developed within the TURKEY/CIMMYT/ICARDA International Winter Wheat Improvement Program hosted by Turkey's Ministry of Agriculture.

Approximately 50 million hectares of wheat land, or close to 50% of all wheat cultivated in developing countries, are located in rainfed (i.e., non-irrigated) systems that receive less than 500 mm of rainfall annually. They represent the most challenging and diverse ecologies in which wheat is grown. A significant portion of this rainfed wheat area receives less than 350 mm annual precipitation and is cropped by more than 5 million of the poorest and most disadvantaged wheat farmers and whose livelihoods depend on income from wheat production. Negative impacts of climate change—more frequent drought, extreme heat, and irregular rainfall distribution—will be particularly pronounced and harmful in this agro-ecosystem.

Wheat provides 20% of all calories worldwide, and nearly all wheat produced in developing countries is for human consumption. In regions like Central and West Asia and North Africa (CWANA), wheat accounts for 40–60% of all calories, which translates into an annual per capita consumption of 180 kg of wheat. This SI is the assembly line where new diversity and outputs from the other Initiatives for wheat (genetic diversity, higher yield potential, enhanced heat and/or drought tolerance, and disease and pest resistance) are combined into superior wheat varieties that possess all the key traits required for adoption by smallholder farmers in developing countries.

Yield plateau and declining trends in wheat yield growth

Global wheat yield growth, measured as average farm yield, declined from 2.8% / year during the period from 1980 – 1994 to 1% 1995-2005 (Dixon et al., 2009) due to various reasons. Low wheat prices caused farmers to reduce inputs, adverse climatic conditions, attractive crop diversity options pushed wheat into less fertile areas, and wheat reaching the genetic plateau for yield increase. Graybosch and Peterson (2010) found that for the Great Plains of the US, improvement in the genetic potential for grain yield awaits some new technological or biological advance. On the other side, Spink et al (2009) argue that wheat yields in the UK can be increased by 30% by 2025 and 50% by 2050, provided significant investments are made in production research. Using data from CIMMYT's International Nurseries distributed from 1970 – 2008, genetic yield progress was measured in subsets of sites in Asia and Africa and grouped into high, intermediate, and low yielding. The genetic yield progress was 0.9, 0.7 and 0.5% year-1 respectively. There was no evidence that genetic gains to increase yield potential has slowed down in CIMMYT germplasm (da Silva, pers comm.). Similar linear yield gains of 0.6% year-1 for 1980 – 2008 were reported by Zheng et al (2011). In spite of conflicting reports on genetic gains for wheat yield potential, there is no doubt that wheat yield gains in farmers' fields have slowed down or even stagnated for the last decade (Fischer et al., 2009, FAO-STATS 2010). The global average wheat yield is at present 3t ha-1 and Fischer et al (2009) have shown average yield gaps of 40% between farmers' yield and economically attainable yield in important wheat based crop-production systems. Bruinsma (2009) calculated that wheat productivity in the 20 major wheat producing countries can be increased by 200 kg/ha in Canada (8%) to 5300 kg/ha in Romania (200%) provided improved wheat cultivars and optimal agronomy practices are used.

Why international agricultural research?

About 70% of the spring wheat areas in developing countries are sown to wheat cultivars that contain contributions from the CIMMYT and ICARDA wheat breeding programs. Nearly 80% of all durum wheat cultivars in developing countries are CIMMYT-ICARDA selections. Virtually all wheat programs worldwide participate in the International Wheat Improvement Network (IWIN), coordinated by CIMMYT and ICARDA, assuring fast, efficient and widespread distribution and use of new wheat lines by partners. The effectiveness of IWIN is illustrated by its role in the wheat research community's rapid response to Ug99, a highly virulent new race of stem rust identified in eastern Africa in 1999 and more recently in South Africa and the Middle East, which threatens large tracts of wheat land in those regions and in Asia. Since 2006, when an expert meeting was held in Kenya, r 18 Ug99 resistant cultivars have already been released of which 14 are of CIMMYT origin and their seed is being multiplied for distribution to farmers in Afghanistan, Bangladesh, Ethiopia, Egypt, India, Iran, Kenya, Nepal, and Pakistan (Singh et al. 2011).

New sources of important traits for wheat breeding have been identified in genebank seed collections, landraces and wild relatives of wheat, and in advanced lines used by partners for crossing and cultivar release. Making new genetic variability available globally is a unique strength of CIMMYT and ICARDA, as no other providers, public or private, maintain a distribution system comparable to IWIN. Of particular relevance was here the impact of synthetic derived germplasm.[13] Through IWIN, improved CIMMYT and ICARDA wheat lines, along with crucial information that facilitates their use—for example, performance data— are freely available to breeding programs worldwide.

The CIMMYT and ICARDA wheat programs conduct more than one crop cycle per year by shuttle breeding lines between diverse environments (see Appendix C for a description of the various breeding schema used).[14] The international centers use global hotspots for specific stresses to select for tolerance or resistance to these stresses, e.g. Kenya for Ug 99, Ethiopia for Ug 99 and Septoria, Eastern Gangetic Plains for spot blotch, Turkey for soil borne diseases and Zn-deficient soils, China for yellow rust and Fusarium head scab, Morocco and Tunisia for rust and Septoria in durum, Uzbekistan for salt in addition to networks to screen for heat and drought tolerance (Sudan, Egypt, Iran, Pakistan, India). The Turkey/CIMMYT/ICARDA International Winter Wheat Improvement Program is entirely based in Turkey and hosted by the Ministry of Agriculture. Drawing on such strategic partnerships with national wheat breeding programs, segregating populations or elite lines developed through collaboration are then shared with the global wheat community through international nurseries or trait specific nurseries targeted at a specific group.

---

[13] Synthetics are derived from a cross between *Triticum durum* and *Aegilops squarosa*, backcrossed once or twice to elite bread wheat lines. Synthetic derived cultivars are released in several countries including China and nearly 50% of all advanced lines at CIMMYT have now synthetic derived lines in their pedigree.

[14] In studies comparing it with breeding methods that employ doubled haploids, the CIMMYT and ICARDA shuttle breeding systems were more efficient in all scenarios (Wang et al. 2008). Further assessments were conducted by Reynolds and Borlaug 2006; Ortiz et al. 2007.

The centers also work closely with advanced research institutes and the private sector to adapt and apply cutting-edge germplasm improvement technologies. CIMMYT and ICARDA have one of the largest wheat marker-assisted selection programs in the public domain, and there is a constant demand for functional markers linked to target traits that are combined with an efficient genotyping platform with many of these markers obtained from cooperators in the US, Australia, Europe and China. The controlled combination of biotic- and abiotic-stress-resistant genes by means of functional markers is an important addition to the wheat breeder's toolbox for developing high-value germplasm. An example is the combination of three to four resistance genes to maximize global diversity for durable rust resistance.

Participatory, open resource technology development, exchange and feedback

The International Wheat Improvement Network (IWIN) is "the annual contact point between CIMMYT and ICARDA and the global network of wheat research cooperators who collaboratively evaluate wheat germplasm. This participatory, open source for breeding of wheat is based on an elaborate network of international nurseries and germplasm exchange, information collection and sharing, human resources development, and workshops and staff exchanges. Improved germplasm from CIMMYT and ICARDA, as well as co-operators who agree by means of MTA to share their material internationally, is dispatched through nurseries targeted to specific (mega-environment defined) agro-ecological environments, to this network of researchers. Data from these trials are then returned by cooperators and partners to CIMMYT and ICARDA, catalogued, analyzed, and made available to the global wheat improvement community. The ultimate beneficiaries of the fruits of this network are farmers" (Payne 2004).

The international wheat nursery system is a very large network. For example, from 1994 to 2000 CIMMYT distributed 1.2 million samples to more than 100 countries—equivalent to the shipment of over 11 tons of wheat seed annually (Fowler et al. 2001). Considerable care is needed to ensure the highest standards of seed health in order to reduce the risk of spreading seed-borne diseases. The seed health units at CIMMYT and ICARDA use international standards to monitor and test all center seed quality.

Nurseries are distributed on the understanding that the shared objective is to develop international public goods freely available to all for increasing food production in the developing world (Byerlee and Dubin 2010). Neither CIMMYT nor ICARDA release varieties, but cooperating partners are encouraged to do so. CIMMYT and ICARDA only request to be informed and permission to release a line is then granted.

Researchable issues

- Yield gains, as the current rate of 1% annual grain growth is insufficient to produce enough food—on the current amount of sown land—to meet the demands of a world population increasing at 1.6% annually (with SI5, 6 and 7).
- Water-use efficiency and drought tolerance (SI3 and SI6).

- Durable resistance to rusts, other major diseases, and pests: maintaining genetic diversity for resistance to avoid genetic vulnerability to evolving and migrating pathogen and pest populations (SI5).
- Heat tolerance (SI6).
- Tolerance to salinity in irrigated areas, in particular in CWANA and South Asia (SI 9).
- Grain processing and end use quality is paramount to all germplasm developed under SI4. Grain quality is difficult to evaluate because of complex genetic control on the grain composition (protein, starch, lipids etc.), as well as various influences from interactions between diverse grain compositional factors during processing, and highly variable end-user preferences (with China)
- Genetic control of complex traits important in end-use and nutritional quality (with CRP4).
- Location and year affects on quality performance, as they relate to yield productivity.
- Genetic diversity-controlling quality traits.
- Integration of a cost-effective molecular breeding platform at international centers and in national programs.
- Mechanisms and strategic partnerships that enable farmer-preferred varieties to reach smallholder farmers in the shortest possible timeframe.

Outputs to 2016

1. An annual increase of 0.9% in genetic yield potential gains maintained in new wheat cultivars and elite lines for Asia, Africa, and Latin America.
2. Elite wheat lines able to maintain productivity in South Asia and other heat-stressed regions with a temperature increase of 1 °C.
3. Elite lines with diverse and durable resistance to all three major rusts in Asia, Africa, and Latin America.
4. Elite lines with resistance to diseases and pests of regional importance other than rust.
5. Elite lines with 20% higher zinc and iron contents, and a 5% increase in grain protein content over that of existing commercial varieties.
6. Parental stocks with salinity tolerance that is better than currently grown cultivars.
7. Marker-assisted selection tools that will facilitate development of salt tolerant wheat lines.
8. Segregating populations developed for specific traits shared with NARS in targeted regions.
9. Enhanced participation of NARS partners in IWIN.
10. Molecular marker and genotyping platform continually optimized and validated for increased application efficiency.

Research and development partners

Research will be carried out in close collaboration with national research programs, advanced research institutes, universities, and the private sector. SI 4 is closely linked with all other nine SIs, as all contribute to the development of improved wheat germplasm. Capacity strengthening for wheat improvement research is a major component, since many national programs have to tackle increasingly complex breeding challenges. CIMMYT and ICARDA will provide support, especially in accessing high-priority traits from cooperating partners, for incorporation and deployment in farmer-preferred varieties. Collaborators will also include IWIN partners and clients: more than 250 public and private breeding programs worldwide, including national research programs, non-governmental and community-based organizations, and farmer associations.

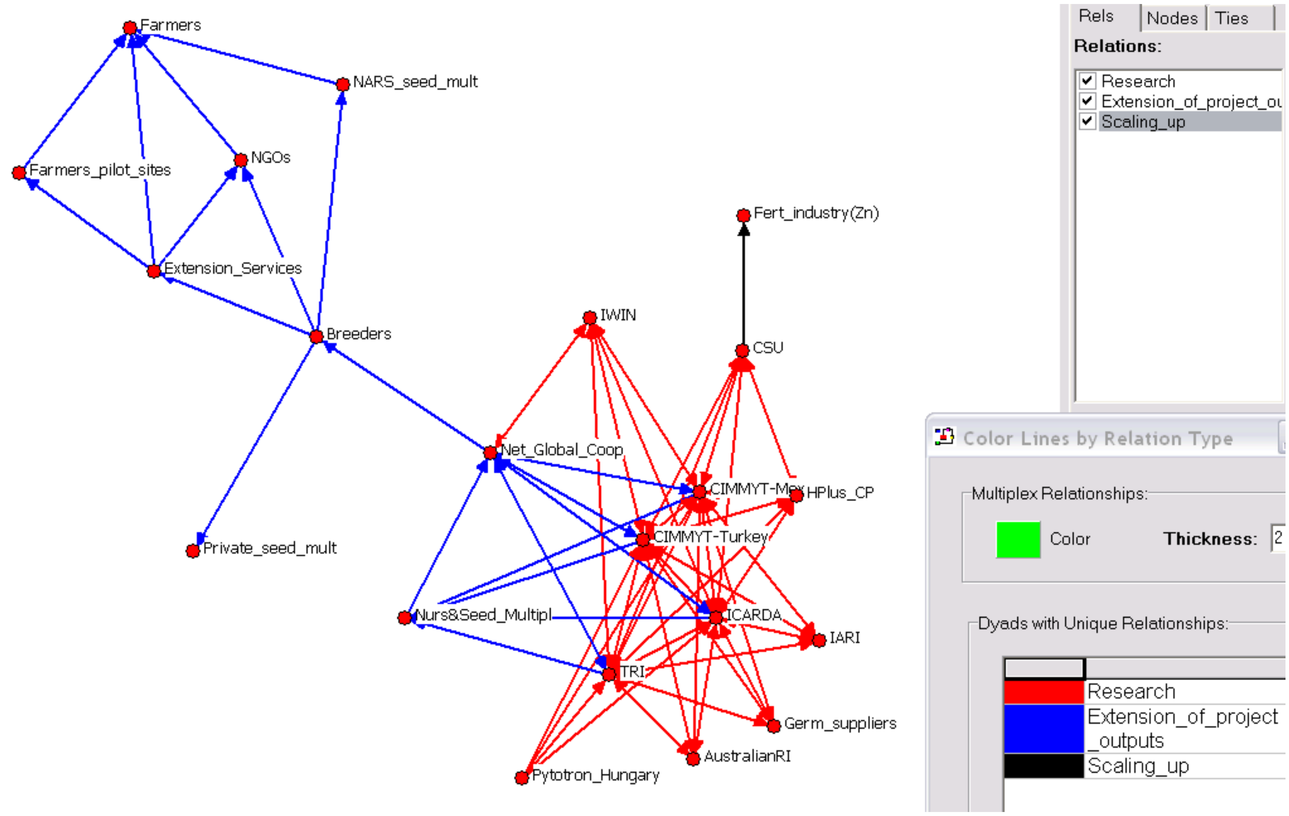


Figure SI 4.1. An Example Network Tree for the TURKEY/CIMMYT/ICARDA Winter Wheat Improvement Program.

A visual example of how the TURKEY/CIMMYT/ICARDA Winter Wheat program in Turkey networks with global partners to develop, test, and globally distribute germplasm is shown in Figure SI 4.1. This program receives germplasm from various public and private sectors' programs and then, from Turkey, breeding materials are distributed to countries that grow winter wheat. Most collaborators in these countries then evaluate the material and send the results to IWIN, where the data are compiled and then sent back to collaborators and breeders—for further research or for variety testing. The other CIMMYT and ICARDA wheat breeding programs follow a similar network tree for germplasm development and testing.

Outcomes

- Effectiveness of partners to utilize international wheat germplasm as parents in breeding programs or to select lines for release is enhanced.
- New elite wheat lines, integrating triats form SI 3, 5, 6, 7, 9, are available for immediate use by partners in crossing programs or for release.

- New elite wheat lines are used by SI2 and SI8 to assure rapid seed dissemination of new cultivars and available to farmers practicing sustainable production systems.
- Income from wheat production is higher and more stable for smallholder farmers who adopt modern wheat varieties resistant to diseases and pests and tolerant to drought and heat stresses caused by climate change.

	2011	2012	2013	2014	2015	2016
Output 1: An annual increase of 0.9% in genetic yield potential gains maintained in new wheat cultivars and elite lines for Asia, Africa and Latin America.	1, 4	1, 4	1, 4	1, 4	1, 4	1, 4
Output 2: Elite wheat lines able to maintain productivity in South Asia and other heat-stressed regions with a temperature increase of 1 °C.	1, 4	1, 4	1, 4	1, 4	1, 4	1, 4
Output 3: Elite lines with diverse and durable resistance to all three major rusts in Asia, Africa and Latin America.	1, 4	1, 4	1, 4	1, 4	1, 4	1, 4
Output 4: Elite lines with resistance to diseases and pests of regional importance other than rust	1, 4	1, 4	1, 4	1, 4	1, 4	1, 4
Output 5: Elite lines with 20% higher zinc and iron contents, and a 5% increase in grain protein content over that of existing commercial varieties (with CRP4).	1, 4	1, 4	1, 4	1, 4	1, 4	1, 4
Output 6: Parental stocks with salinity tolerance that is better than currently grown cultivars,				1	1	1
Output 7: Segregating populations developed for specific traits shared with NARS in targeted regions	2	2	2	2	2	2
Output 8: Molecular marker and genotyping platform continually optimized and validated for increased application efficiency	5	5	5	5	5	5
Output 9: Enhanced participation of NARS partners in IWIN	3, 6	3, 6	3, 6	3, 6	3, 6	3, 6

*Refer to numbered milestone descriptions in the text

Key milestones

SI4 brings together the products and knowledge from other SIs to develop wheat germplasm for immediate use by partners in the form of segregating population, parental lines for crossing or candidate lines for release. Milestones are mainly in the form of elite lines and genetic stocks distributed through international nurseries. These nurseries are the main vehicle for providing cooperators with germplasm from CIMMYT, ICARDA and where permitted other cooperators.

1.	Annually distribute more than 1,000 genetically diverse lines to more than 250 cooperators; lines include spring and facultative durum wheat, spring bread wheat, and winter wheat with high yield potential, durable disease resistance, drought and heat tolerance, nutrient-use efficiency, and end-user, value-added grain quality traits. Depending on the targeted region, these lines will also possess resistance (developed through SI 5) to one or more of the following diseases and pests: Septoria, tan spot, Fusarium head scab, Helminthosporium leaf blight, soil-borne diseases (nematodes, crown and root rots), Sunn pest, Hessian fly, Russian wheat aphid, green bug, and barley yellow dwarf virus.	*Annually*
2.	Annually distribute segregating population for targeted traits.	*Annually*
3.	International performance results analyzed and distributed to all collaborators annually.	*Annually*
4.	At least 10 cultivars resulting from SI collaboration released by national program partners.	*Annually*
5.	Annually, more that 80,000 marker data points produced for breeders' selection in the field.	*Annually*
6.	Validated markers for important traits available for use by NARS partners.	*Annually*

What's new in this initiative?

Modern tools, including genome-wide selection, high-throughput marker-assisted selection, and advanced statistical analysis of multi-location evaluation data (which is used in wheat breeding to allow faster integration of desirable traits and improve breeding efficiency—especially for complex traits such as grain yield under optimum drought and heat conditions). CRP-level investment, in comparison with fragmented short-term funding from individual donors, will make it possible to increase research efficiency and develop, test and disseminate robust wheat varieties that improve the lives of smallholder farmers. Close links with other SIs and CRPs (1, 4, 7) assure rapid and enhanced use of genetic potential of improved wheat germplasm.

Targeting and impact estimates

Outputs of this SI are targeted toward more than 90% of the entire wheat growing area in the developing world. Wheat environments in developing countries are diverse, and have been classified by CIMMYT into 12 mega-environments (ME), of which MEs 1–6 comprise spring wheat regions, MEs 7–9 facultative wheat zones, and MEs 10-12 winter wheat environments.

Table 2 presents the WHEAT prioritization based on megaenvironment; related wheat area; affected population earning less than USD 2 per day; and associated representative locations.

- High priority megaenvironments and regions: ME1 (affecting 556m people earning less than USD2 per day in West and South Asia, Egypt and Mexico); ME2 (affecting 107m people in East and North Africa); ME4 (affecting 75m people primarily in CWANA and India); ME5 (affecting 238m people primarily in South Asia); and ME12 (affecting 14m people in CWANA and China).
- Medium priority megaenvironments and regions: ME6 (affecting 10m people in China, Kazakhstan and Siberia); ME7 (affecting 89m people in CWANA and China); ME9 (affecting 7m people in CWANA); and ME10 (affecting 66m people in CWANA and China).
- Low or no priority megaenvironments and regions: ME3 (affecting 16m people in Brazil); ME8 (affecting 2m people in Chile and Turkey); and ME11 (which primarily affects Europe and North America).

Table 1 and Table 2 provide detailed information regarding the importance of each of these criteria for each geographic region and mega-environment. Biotic stresses are further prioritized in Table 5.1 based on area where they occur and potential economic losses they cause. Further details are provided by Braun et al. (2010). Priorities were based on refereed journals, expert opinions, country reports from national wheat programs, and data presented at conferences on specific diseases. WHEAT's SI 1 will continue to work with CRP 2, CRP 7, and other WHEAT SIs to continually inform and update research priorities and strategies to maximize impacts.

Impact estimates

- Increased production by 2.1 million annually by 2020 and 2.5 million annually by 2030.
- Increased wheat productivity will stabilize wheat prices at affordable levels for rural and urban poor.
- Higher-yielding wheat cultivars with enhanced input use efficiency reduce pressure to expand wheat area into natural ecosystems and may reduce wheat area in marginal, fragile environments.
- Reduced pesticide use due to wheat cultivars with resistance to a wider spectrum of diseases and resistance to insects.
- Stress tolerant wheat cultivars reduce vulnerability of resource-poor farmers to losses from biotic and abiotic stresses.
- The current threat of stem rust will trigger faster adoption of higher-yielding resistant varieties. We estimate that 10 million hectares (13% of the area) will be occupied by higher-yielding resistant varieties with adult plant resistance to rusts by 2020, and 30 million hectares (40% of the area) by 2030, preventing yield losses of 10% in both 2020 and 2030.

Other issues

Gender

Gender-disaggregated data from participatory variety selection trials will ensure that women's voices are captured in the selection of varieties to be nominated for national performance trials. Women historically have been excluded from gaining higher shares in value chains. Strategies to add value can help meet equity and efficiency objectives. One approach is by adding value to products, for example breeding varieties with quality, nutrition and food safety traits favored by end-users in mainstream and niche markets (for example, plump bold grain, high yellow pigment durum, bio-fortified grain, organic food chains etc.). For women to capture higher financial benefits, assistance must be provided for them to become crop production specialists (linked to SIs 2 and 10) while still maintaining a clear market orientation. In this case, "market" can be defined as an economic opportunity to exchange inputs, products, or knowledge. Opportunities for value-adding for women may exist through an upgrade of their current role in a value chain; moving up to additional roles in value chains; finding new products and becoming dominant members of a new value chain; and increasing efficiency in their current role in the value chain. All are based on concrete analysis of the markets and value chains (in SI 1) with a gender lens. At the minimum, such an analysis should ensure that women and other disadvantaged members of chains, or women in sectors impacted by the chain, are not negatively affected by the way the chain is organized and functioning.

Lessons learned

Comparisons of breeding methodologies through head-to-head experiments can be made in field trials, or increasingly common are modeled simulation comparisons. The single backcrossing bulk breeding strategy used by CIMMYT and ICARDA has been shown to be highly effective (Wang et al. 2008). A comparison between the shuttle breeding systems used by CIMMYT, where two generations per year are screened in diverse environments for multiple traits, and doubled haploids rapid generation advancement showed shuttle breeding achieving greater gains per unit time (Wang pers. comm.). To select for resistance to Ug99, F3 and F4 populations are evaluated in Kenya, with final selection for grain yield potential occurring in Mexico. The constant evaluation of breeding methods assures that resources are used in the most efficient ways and genetic gains are maximized.

Research methods[15]

- Progress will continue to be made through the adaptation of breeding methodologies that emphasize the use of largely pedigree selection, including some modifications such as the selected bulk method in combination with shuttle breeding, the use of germplasm with broad adaptation, and traits networks.
- Doubled haploid and single seed descent routinely used in breeding efforts, where it has the advantage of reducing the breeding and germplasm development efficiency.

[15] Detailed methodologies relevant to SI 4 implementation can be obtained upon request through the Global Wheat Program Annual Reports (2007, 2008, 2009); Cropping Systems Initiative for South Asia (2008); Durable Rust Resistant Wheat (2010). Also see Annex C.

- Advances in technology necessitate the increased deployment of marker-assisted selection (MAS) and genomic selection to fast-track the incorporation of trait(s) into desirable genetic backgrounds (with SI 9). These would be used in tackling traits with hitherto complex inheritance and ensuring the durability of resistance to diseases and pests, including maintaining genetic diversity for resistance to avoid genetic vulnerability from evolving and migrating pathogen and pest populations. MAS would be deployed to pyramid major and minor disease-resistance genes into elite germplasm, imparting enhanced durability and mitigating the impact of a potential breakdown in resistance as a result of newly evolved virulence to currently deployed genes.
- Multi-location, multi-environment and multi-year testing of germplasm, by CIMMYT and ICARDA together with global IWIN partners, will remain central to our breeding approaches.

References

Braun, H.J,, Atlin, G. and Payne, T. 2010. Multi-location testing as a tool to identify plant response to global climate change. In: Reynolds, C.R.P. (ed.), Climate Change and Crop Production, CABI, London, UK.

Bruinsma, J. 2009. The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050? Expert Meeting on How to Feed the World in 2050. Rome, FAO.

Byerlee, D. and Dubin, H.J. 2010. Crop Improvement in the CGIAR as a global success story of open access and international sharing. *International Journal of the Commons* 4(1): 452–480.

Fischer, R.A., D. Byerlee and G.O. Edmeades. 2009. Can Technology Deliver on the Yield Challenge to 2050? Expert meeting on "How to Feed the World in 2050", FAO, Rome, 24-26 June 2009.

Fowler, C., Smale, M. and Gaiji, S. 2001. Unequal exchange? Recent transfers of agricultural resources and their implications for developing countries. *Development Policy Review*, 19(2): 181–204.

Graybosch, R.A. and C. J. Peterson. 2010. Genetic improvement in winter wheat yields in the Great Plains of North America, 1959-2008. Crop Science. 50, 1882-1890.

Ortiz R, Trethowan, R.M,, Ortiz Ferrara, G., Iwanaga, M., Dodds, J.H., Crouch, J.H., Crossa, J.and Braun, H.J. 2007. High yield potential, shuttle breeding, genetic diversity, and a new international wheat improvement strategy. *Euphytica* 157: 365–384.

Payne, T. 2004. The international wheat improvement network (IWIN) at CIMMYT. www.cimmyt.org.

Reynolds, M.P. and Borlaug, N.E. 2006. Impacts of breeding on international collaborative wheat improvement. *Journal of Agricultural Science* 144: 3–17.

Singh,R.P., D. P. Hodson, J. H.Huerta-Espino, Y. Jin, S. Bhavani, P. Njau, S. Herrera-Foessel, P. K. Singh, S. Singh and V. Govindan. 2011. The Emergence of Ug99 Races of the Stem Rust Fungus is a Threat to World Wheat Production. Annu. Rev. Phytopathol. 2011. 49:13.1–13.17

Spink, J., P. Street, R. Sylvester-Bradley and P. Berry. 2009. The potential to increase porductivity of wheat and oilseed rape in the UK. Report to the Government Chief Scientific Advisor, Prof. John Beddington.

Wang Jiankang, Singh, R.P., Braun, H.J. and Pfeiffer, W. H. 2008. Investigating the efficiency of single backcrossing breeding strategy through computer simulation. TAG. Published on-line Nov 26, 2008.

Zheng, T. C., X. K. Zhang, G. H. Yin, L. N. Wang, Y. L. Han, L. Chen, F. Huang, J. W. Tang, X. C. Xia, Z. H. He, 2011. Genetic Gains in Grain Yield, Net Photosynthesis and Stomatal Conductance Achieved in Henan Province of China between 1981 and 2008. Field Crop Research. In press.

Strategic Initiative 5. Durable resistance and management of diseases and insect pests

Value proposition

Safeguard global wheat production in developing countries through enhanced genetic resistance to diseases that each cause significant economic losses on 5-50 million hectares, and to pests and viruses that each affect 2-10 million hectares; improve food safety and quality by reducing mycotoxin levels in grain; and reduce pesticide use, thereby increasing farmers' profits and protecting the environment. This SI will protect the yield gains obtained through other SIs.

Estimated impact	2020	2030
Annual production increase	3.2 million tons of wheat grain saved, due to 10% reduced losses from biotic stresses.	10.1 million tons wheat grain saved, due to 20% reduced losses from biotic stresses.
Benefit to the poor	Provide wheat for an additional 30 million consumers at 100 kg/capita/year; increase the income of farmers, who in turn produce safer wheat grain at a lower cost for both rural and urban consumers.	
Benefit to the environment	Minimize use of pesticides through deployment of disease- and pest-resistant wheat varieties and adoption of integrated pest management (IPM).	
Annual value addition	USD 704 million. A regional cereal rust epidemic in Asia could cause losses of more than USD 2 billion per year.	USD 2.424 billion.
Others	Strengthen national programs through training in modern breeding and IPM tools, leading to the adaptation and adoption of research technologies that increase annual wheat production in developing countries by over 1.6% per annum.	

Justification

General background

The World Bank estimates that every 1% increase in wheat productivity reduces poverty by 0.5 to 1.0% (World Bank 2008). Under current pest and disease control practices, losses to pathogens, pests, and viruses are estimated at 13% (Oerke 2006), equivalent to 45 million tons of wheat per year and valued at USD 9 billion in developing countries. Climate change and globalization come with new risks of pest and disease outbreaks. A coordinated effort is needed to develop wheat cultivars that are resistant to new races of pathogens that threaten global wheat production.

Breeding for resistance offers the most environmentally sustainable approach to pest and disease control, allowing farmers to reduce pesticide inputs, increase profit margins, and keep wheat prices affordable for urban and rural consumers. While host resistance remains the foundation of disease and pest control, cultural practices and biological control through integrated pest management (IPM) are an integral part of wheat disease and pest (insect) management. Integrated pest management approaches, built on a combination of resistant cultivars and sound knowledge of host-pathogen interactions, aims to discourage virulent/new pest population development and keep pesticide interventions at levels that are economically justified and safe for human health and the environment.

The use of resistant cultivars in combination with cultural practices (early planting dates, fertilizer inputs and stand establishment) has been a good IPM option to reduce Hessian fly damage in North Africa. Enhancement and conservation of natural enemies and insect-killing fungi are promising IPM options for Sunn pest management in Asia. Proper crop rotations in association with fertilizers and responsible pesticide use offer alternative disease management options for soil (cereal cyst nematode, root rot) and stubble (Septoria and Tan spot) diseases in many wheat-growing areas under rainfed agriculture.

Why international agricultural research?
Over the last 40 years, two major cereal rusts of global importance—leaf and stem rust—have been controlled through adoption of resistant cultivars in developing countries. But yellow rust epidemics, in particular in CWANA region, remain a major challenge and require an internationally coordinated effort equal to investments in Ug99 (stem rust). Wheat diseases often occur in diverse ecosystems and geographically very distant regions—spores can travel over thousands of kilometers in days. Wheat breeding programs at CIMMYT and ICARDA allocate around 50% of their budgets to maintenance breeding and novel breeding challenges for disease and pest resistance, using extensive testing through global networks to develop germplasm that is resistant to key pests and diseases in developing countries. These networks also serve as early warning systems for new races and diseases and provide unique access to hot spots for reliable disease and pest screening.[16] Finally, wheat researchers worldwide identify and use new sources of resistance from the CIMMYT and ICARDA genebanks, whose seed collections represent a significant portion of the global diversity of wheat wild relatives and modern cultivars.

Wheat germplasm from these international centers is adapted to nearly all wheat-growing environments in developing countries, and new sources of resistance from these centers is extensively used by national, other public, and private research programs. Often for lack of resources, or simply to enhance research efficiency, national programs and private sector partners look to international centers for collaboration and leadership to identify and transfer resistance genes into elite germplasm, a process that can take more than 10 years.

Together, CIMMYT and ICARDA have a comparative advantage in developing elite wheat germplasm that is high yielding and resistant to multiple pests and diseases—thus protecting wheat farmers in developing countries from major losses. Approaches like shuttle breeding, double haploids, and use of

[16] This approach has recently resulted in the rapid development of wheat lines that are resistant to wheat stem rust race Ug99, detected in 1998 and virulent on most currently grown wheat cultivars. Countries where stem rust is a potential threat to their wheat production have sent more than 45,000 accessions to hot spots in Kenya and Ethiopia for evaluation to identify Ug99 resistance, and resistant varieties are currently in seed multiplication.

molecular markers shorten the time needed to develop new varieties. Teams of CIMMYT and ICARDA wheat specialists are based in strategic locations in Afghanistan, Bangladesh, China, Ethiopia, India, Iran, Kazakhstan, Kenya, Morocco, Nepal, Pakistan, Sudan, Tunisia, Turkey, and Uzbekistan. They work with national research systems and have established decentralized breeding networks to rapidly identify and develop new germplasm. Where possible, farmer participatory approaches are used to accelerate seed delivery and production, raise farmers' awareness about new varieties, and feed their demands back into breeding research.

In summary, pest and disease control methods proposed in this SI are based on breeding for resistance and the use of IPM. Chemical control options would be limited to the evaluation of reasonable use of fungicides or pesticides in very specific cases where no other alternative is available, or when the threat on food security is deemed to be too high.

Researchable issues

- Development and use of molecular markers to introduce combinations of minor and major rust resistance genes into adapted cultivars (with SI 4).
- Marker application to combine multiple disease and insects resistance (with SI 4).
- Climate change alterations in soil microbial systems and the distribution and severity of weeds, insects, and diseases. Examples include spot blotch in wheat on the Gangetic Plains, Sunn pest and aphids, and aphid-transmitted diseases like barley yellow dwarf virus (with SI 2).
- Developing integrated management options for key diseases and pests for farmers (with SI 2).
- Soil borne diseases/pests such as nematodes and root rots and their control (essential for enhancing drought tolerance in rainfed wheat).
- Conservation agriculture in terms of spread and control of associated diseases. It is known that some diseases may increase with CA practices, hence high priority will be given to Fusarium head scab, Tan spot, and Septoria (with SI 2).
- Fusarium head blight and related mycotoxins in wheat-maize cropping systems.
- Wheat blast in Brazil, Paraguay, and Bolivia and the potential of this disease to move to the rice-wheat cropping systems in Asia. There is tolerance, but no effective adult plant resistance is known.
- Reclassification of disease and pest hot-spots according to climatic changes, and continuing of multi-location testing to identify potential breakdowns in disease-resistance genes or the evolution of new pathotypes (with SI 1).
- New gene discovery for stressed environments, particularly for heat and moisture stress, which predispose wheat to diseases such as spot blotch and root pathogens (with SI 9).
- Global understanding of pathogen populations using conventional and molecular approaches.
- Better seed health and quarantine procedures to ensure safe, free movement of seed (with SI 8).

SI 5 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: High-yielding wheat genotypes with disease resistance tested and released.	**1***	**1, 2**	**1, 2, 4, 5, 6**	**1, 2, 7**	**1, 2, 8, 9**	**1, 2, 11**
Output 2: Molecular markers for rust genes identified.		**2**	**4, 5**		**9, 10**	
Output 3: New genes for head blight resistance identified.		**2, 3**				
Output 4: Monitoring and early warning systems developed for emerging diseases.					**9**	**11**
Output 5: Integrated pest management system developed for key pests (with SI 2).		**2**			**8**	
Output 6: Sources of resistance to wheat blast identified- (with SI 1 and 9).		**2, 3**	**6**			
Output 7: Grassy relatives of wheat characterized for rust and blast resistance (with SI 9).		**2, 3**	**5, 6**		**9, 10**	
Output 8: Transgenic options assessed for disease resistance ‡.						
Output 9: Integrated management approaches for key pests and diseases validated and integrated (with SI 2).			**5**	**7**	**8, 9**	**12**

*Refer to numbered milestone descriptions in the text

‡ Currently no milestones are proposed; these will be developed as opportunities arise

SI 5 Key Milestones

1.	Foundation seed is produced (with SI 8) of cultivars resistant to Ug99 and other regionally important diseases in Afghanistan, Bangladesh, Egypt, Ethiopia, India, Nepal, and Pakistan (total more than 1,000 tons).	*2011*
2.	Multiple disease and insect resistance incorporated into more than 50% of durum and bread wheat lines targeted for North Africa.	*2012*
3.	Pre-breeding begins (with SI 9) to incorporate more diverse resistance genes from grassy relatives of wheat into modern cultivars.	*2012*

4.	Molecular markers identified for spot blotch and Septoria are used in bread- and durum-wheat breeding.	*2013*
5.	Markers for adult plant rust resistance are available for use by national research systems.	*2013*
6.	Transfer of sources of wheat blast resistance into high-yielding cultivars initiated.	*2013*
7.	Resistance to soil borne diseases incorporated into elite winter and spring wheat lines and distributed to cooperators.	*2014*
8.	Ten Sunn pest resistant lines distributed to cooperators.	*2015*
9.	Area sown to Ug99-resistant wheat varieties in developing countries increases to 5 million hectares.	*2015*
10.	Resistance to yellow rust is identified and transferred into modern cultivars.	*2015*
11.	Cultivars resistant to Helminthosporium spot blotch are grown by more than 2 million farmers in the Eastern Gangetic Plains.	*2016*
12.	Integrated pest management systems available (together with SI 2) for use by farmers.	*2016*

Outcomes

- Elite lines which reduce the vulnerability of smallholder farmers to disease and pest losses are used by researchers and farmers.
- National research systems are empowered through new research tools, information, and more effective collaboration.
- Better pest and disease resistance and control technologies that can increase wheat yields by 0.5% per year are used by researchers and farmers.
- New molecular markers for resistance to rust and other diseases allow diverse gene combinations—and thus durable disease resistance—in improved varieties.
- New genes for Fusarium head blight (FHB) resistance that reduce mycotoxin content in wheat grain by 50% are used by researchers.
- Integrated pest management options are available to reduce pesticide use and increase food safety.

Targets and impact estimates

The outputs of this SI are targeted at more than 90% of the entire wheat growing area in developing countries through a global wheat network that includes over 200 breeding programs in the public and private domains. Due to the size of the target region, multi-stakeholder approaches are used for delivery of wheat technologies. Regional priorities for wheat breeding are based on their economic importance within a given region (Table SI 5.1). Farmers are the ultimate beneficiaries and are generally reached through national programs.

Disease monitoring and surveillance at regional and continental levels will become more important in coming years with the development of remote-sensing technologies. Remote sensing and GIS technologies will be used to monitor population dynamics and spread of diseases and insect pests, particularly in trends of climate change. In fact, we have initiated collaborations with HarvestChoice Partners including IFPRI and are pioneering the development of disease risk assessment maps using modeling techniques. Likewise, using climatic homologies, we intend to determine the risk of wheat blast transfer to more vulnerable regions in terms of food security. Near real-time risk assessment is also done using wind trajectories in the Rustmapper system. New initiatives should be considered with the development of remote sensing in collaborations with ARIs and big NARSs. Yet, as of now, current models and remote sensing based on satellites can barely recognize wheat from other cereals.

The current threat of stem rust will trigger fast adoption of resistant varieties. We estimate that 5 million hectares (13% of the area) will be occupied by resistant varieties with adult plant resistance to rusts by 2020, and 15 million hectares (40% of the area) by 2030, preventing yield losses of 10% and 20% in both 2020 and 2030.

The potential benefit of using remote-sensing and modeling technologies to determine risks of disease outbreaks has been highlighted. Yet, the impact of breeding, especially strategic breeding priorities for biotic stresses, will continue to be highly dependent on accurate yield loss estimates from these individual pests and diseases. Annual value additions and production increases are based on estimates by Oerke (2006), which are among the very few quantified estimates determined by crop protection specialists. The need for similar information in developing countries will continue to be high in future and can only be collected in partnership with SI 1 and NARS, and with an international perspective.

Research and development partners

Collaborative research is conducted with other WHEAT SIs, CGIAR centers, national research systems, and the private sector. Capacity building for pathology research is a major component. In-service training at CIMMYT and ICARDA enables local hot spots for key diseases and pests to contribute to the global wheat network. Areas of upstream collaboration with advanced research institutes include pathogen diversity and genomics studies, also disease epidemiology and modeling. Given the vast investment of other partners (advanced research institutes and the private sector) in genetic research, CIMMYT and ICARDA will focus on priority disease- and pest-resistance traits for incorporation in, and deployment of, farmer-preferred cultivars in targeted low-income countries. Molecular marker development will combine CIMMYT's and ICARDA's scientific strengths in phenotyping and genotyping with those of universities, research departments of ministries of agriculture, and the private sector.

ICARDA has considerable expertise in IPM to control Sunn pest, showing that according to the needs (in absence of effective resistance) alternatives such as use of IPM are followed. In the case of Sunn pest, parasitic innocuous fungi that destroy the insects are used to reduce populations of Sunn pest. In collaboration with SI 1 and 2, the use of participatory approaches such as farmer field schools (FFS) should accelerate the adoption of IPM technologies. The farmer field school approach has been successfully tested for management of insect pests in Asia (Sunn pest) and North Africa (Hessian fly). This approach has been successfully implemented by FAO in other cropping systems.

Other issues

Gender

Twenty to forty percent of the world's potential crop production is lost annually because of the effects of weeds, pests, and diseases (CropLife International 2007). In some crop agro-economic systems, the control of agricultural pests has been dominated by chemical control strategies. As with so many capital-intensive technologies, the poor, including women and children, are the ones least able to benefit from chemical use. Additionally, they are the most affected by the ill-effects of chemical use. Such monotypic strategies are abhorrent to the philosophies that drive the CIMMYT and ICARDA mission to promote sustainable, productive agricultural eco-systems. Since our inception, use of native genetic diversity to control diseases and pests has been the pillar of our germplasm and technology development activities.

Both centers will continue to act as honest brokers in attempt to bring the best technologies—those that increase livelihoods and sustainability, and are healthy for both the farmer and the environment—to disadvantaged, resource-poor farmers. We do this by following principles of integrated pest management, which aim to enhance crop production based on an understanding of ecological principles that empower women and men farmers to promote the health of crops within well-balanced agro-ecosystems; and to make full use of available technologies, especially durable genetic host resistance, and biological and cultural control methods. Chemical pesticides are used only when the above measures fail to keep pests below acceptable levels, and when assessment of associated risks and benefits (considering effects on human and environmental health, as well as profitability) indicates that the benefits of their use outweigh the costs. All interventions are need-based and are applied in ways that minimize undesirable side effects.

Lessons learned

Over the past decade, the quality and to lesser extent the quantity of nursery evaluation data from NARSs and the private sector has declined. NARS and private-sector scientists remain interested in receiving germplasm from CIMMYT and ICARDA—because they do not want to miss a chance to receive novel and improved materials—but do not always have the resources to participate in collaborative evaluation. Although at some key locations outreach colleagues can help foster better data collection and return, we need more capacity (people, time and resources) to visit and monitor WHEAT trials, and WHEAT will consider other mechanisms to facilitate greater partner participation.

For Helminthosporium spot blotch in South Asia, significant and continual multi-year funding with the flexibility to assign limited and defined operating research funds to NARSs and students at local universities has allowed capacity building and generation of applied, problem-solving research of publishable quality. As a result, we now understand the disease better, have answered specific technical questions as they arose, published nearly 20 papers in internationally refereed journals, and locally trained about 10 MSc students, most of whom have continued on to PhD. studies in advanced research institutes.

Projects connected with advanced research institutes in Europe, the USA, and China are important for successful disease breeding for CIMMYT and ICARDA, because both centers often have difficulty receiving foreign disease samples or reference strains, due to phytosanitary restrictions and a lack of confinement facilities. In foliar blights (tan spot and spot blotch) and bacteria, working with UCL Belgium for keeping strains, sample identification and expertise, as well as visits to NARSs (Central Asia, South Asia, South America) was key to the development of CIMMYT's foliar blights expertise. Similarly, collaboration with the Cereal Disease Lab in Minnesota has allowed synergies on rust research over the years, most recently with Ug99 wheat stem rust.

Research methods

Minor gene-based "adult plant resistance" is the primary means of delivering durable resistance for biotic stresses, diseases, and pests that rapidly evolve. Minor (race non-specific, adult plant resistance, slow rusting, horizontal resistance) genes are a class of genes that have small individual effects and cannot suppress an epidemic or infection event unless combined or pyramided with other minor genes. The co-presence of a major gene masks the presence of any minor genes. In contrast with major genes, minor genes are generally thought to have the same suppressing effect on disease development irrespective of the race of the attacking rust. Resistance based on minor genes is consequently considered race non-specific and therefore durable over time. The minor resistance genes only restrict disease development at the adult (post-seedling) stage, so they are often called adult plant resistance (APR) genes. If all varieties in a region are protected by a single, major gene, and a disease or pest emerges that can overcome that gene, the result can be a catastrophic change from a disease or pest-free crop one season to a badly damaged crop the next. WHEAT is committed to using durable sources of resistance to diseases and pests.

Resistance breeding is fully part of IPM approaches and is particularly eco-friendly, since it avoids or minimizes the use of fungicides and other pesticides. CIMMYT is involved in the Systemwide Program on Integrated Pest Management (SP-IPM), which is CGIAR-wide initiative under the umbrella of the International Institute of Tropical Agriculture (IITA). This program intends to raise funds and awareness on the need to work on IPM approaches, and already a "white document" that aligns IPM with Consortium Research Programs has been prepared. Flagged issues are related to: (1) the reduction of mycotoxins in the food chain, particularly those due to FHB; (2) reduction of nematodes by promoting relevant cropping practices and rotations in legume-based systems. Control of aphids through natural parasites would be a new area of investigation requiring an entomologist.

Table SI 5.1. Regional priorities for biotic stress initiatives in wheat[1].

Biotic stress	East Asia	South Asia	West Asia	Middle East North Africa	Central Asia/Caucasus	Sub-Saharan Africa	Latin Amer. incl. Mex	Areas where economically significant losses can occur (mlln ha)	Developed countries
Leaf rust [2]	++	+++	+++	+++	+++	++	+++	50	++
Stem rust [3]	+++	+++	+++	+++	+++	+++	+++	50	+++
Yellow rust	+++	++	+++	+++	+++	+++	+	40	+++
Fusarium head scab [4]	+++	0	+	0	0	0	++	10	+++
Septoria	+	0	++	+++	++	++	++	11	+++
Spot blotch /*H.. sativum*	+	++	0	0	0	+	+	11	0
Nematodes	++	++	+++	++	0	+	+	10	+
Tan spot [5]	0	+	0	+	+++	0	++	7	++
Smuts and bunts [6]	+	+	++	++	+	+	+	5	0
Wheat blast [7]	0	0	0	0	0	0	+	1	0
Powdery mildew	++	+	0	0	0	0	+	6	++
Root diseases [8]	++	+	++	++	+	+	+	9	+
Insects									
Sunn pest	0	0	+++	+	++	0	0	10	+
Hessian fly	0	0	0	+++	+	0	0	2	+
Russian wheat aphid	0	0	+	+	+	++	+	2	+
Green bug and other common aphids	++	++	0	++	+	+	+	10	+
BYDV and other viruses [9]	+	+	+	+	+	+	+	4	

$^{+++}$ = very important, $^{++}$ = important, $^{+}$ = local importance, ^{0} = not important

[1] The priorities for each disease was defined based on refereed literature (see references), non-refereed publications and country reports from national wheat experts, CIMMYT and ICARDA scientists, and personal communication with NARS scientists .

[2] Leaf rust is currently under genetic control in Asia and Africa, but without maintenance breeding it is a major threat.

[3] Ug99 is currently confined to Ethiopia, Kenya, Uganda, Sudan, Yemen, and Iran; but poses threats to global wheat production.

[4] FHS is expected to expand with conservation agriculture and maize-wheat rotation.

[5] Currently mainly important in Latin America and Central Asia, but will increase with expansion of zero-tillage.

[6] Historically important but effective and inexpensive seed treatments widely used.

[7] Only of local importance in Brazil, Paraguay, and Bolivia; however the fungus is same species as rice blast and could potential pose a threat to wheat production in warm areas of Asia where wheat-rice is grown; no resistance in wheat and limited tolerance.

[8] Includes sharp eye spot.

[9] Of local importance but currently not prioritized in CGIAR breeding programs due to resource limitations.

What's new in this initiative?

Sustained disease and pest monitoring systems, combined with molecular markers and screening tools in wheat improvement, will allow a much faster response to new races and pathotypes of existing diseases and pests, as well as emerging biotic stresses. It will enable a suite of complex traits to be combined, thus reducing the adverse effects of abiotic stresses associated with climate change.

References

Bockus., W.W., R. L. Bowden, R. M. Hunger, W. L. Morrill, T. D. Murray and R.W. Smiley. 2010. Compendium of Wheat Diseases and Pests. 3rd Edition. APS Press, St. Paul, Minnesota.

Crop Protection Compendium. 2007. CABI, Oxfordshire, UK. www.cabicompendium.org/cpc

Duveiller E, R.P. Singh, and J.M. Nicol. 2007. The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. Euphytica 157: 417-430

Luck, J., M. Spackman, A. Freeman, P. Trebicki, W. Griffiths, K. Finlay and S. Chakrabortya. 2011. Climate change and diseases of food crops. Plant Pathology 60: 113-121.

Murray G.M., and J.P. Brennan. 2009. Estimating disease losses to the Australian wheat industry. Australian Plant Pathology 38: 558-570.

Oerke, E.C. 2006. Crop losses to pests. Journal of Agricultural Science 144: 31–43.

Singh, R., H. M. William, Julio Huerta-Espino and Garry Rosewarne. 2004. Wheat Rust in Asia: Meeting the Challenges with Old and New Technologies. In. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 26 Sep – 1 Oct 2004

World Bank. 2008. Agriculture for Development. World Development Report, 2008.

Strategic Initiative 6. Enhanced heat and drought tolerance

Value proposition

Reduce the threat to the livelihoods of resource-poor farmers by applying new genetic and physiological technologies to stabilize wheat productivity in areas of the developing world that are vulnerable to heat and drought stress, or may become vulnerable through the anticipated effects of climate change.

Estimated impact	2020	2030
Increased annual production	First variety releases.	5.8 million tons.
Benefit to the poor	Poor farmers less vulnerable to crop losses from rising temperatures and decreasing water availability. All wheat growers in the developing world will benefit from higher and more stable yields. Urban poor will benefit from food security and affordable wheat prices.	
Benefit to the environment	Higher and more stable yields, especially in marginal environments, reduced pressure to cultivate already fragile ecosystems; improved water-use efficiency in existing wheat systems reduces pressure on scarce water resources.	
Annual value addition		USD 1.392 billion

Justification

General background

High temperature and drought stress currently limit wheat productivity in much of the developing and developed world and, as a result of climate change, will increasingly affect wheat production globally. Conventional breeding (SI 4) and innovative crop management approaches (SI 2) will provide an essential baseline to this SI. Though the genetic bases of the responses are not necessarily the same, crops respond similarly to both stresses: life cycle is accelerated; photosynthetic capacity diminishes due to restricted leaf area and its duration is reduced; metabolism is inhibited at temperature and water ranges outside those optimal for growth; and reproductive processes are impaired when stress occurs at critical developmental stages, reducing seed set. Given the scope and pace of global warming, and because it takes 10 years or more for breeding to achieve impacts in farmers' fields, a well coordinated, multidisciplinary international effort is needed—both to avoid crop failures in regions at greatest risk from climate change and to deploy new technologies for vulnerable farmers.

Between 25 and 30 million hectares of wheat in tropical and subtropical areas (including China, Bangladesh, Nepal, India, Pakistan, Ethiopia, Sudan, Egypt, and North Africa) are subject to yield losses from heat stress (Table SI 6.1). This area will increase substantially, according to current trends and predictions about global warming. In India alone, the heat-stressed wheat area is expected to triple by 2050 and temperatures are projected to rise as much as 3–4 °C by the end of the century. The greatest impacts will be in the Eastern Gangetic Plains, an area with high levels of rural and urban poverty (Braun et al. 2010).

Of the three major staple crops, wheat is the best adapted and the most widely grown under semi-arid conditions. The majority of the 110 million hectares of wheat grown in the developing world is already experiencing temporary or permanent water scarcity, as a result of either inter- or intra-seasonal rainfall variation (in rainfed systems) or of temporary unavailability of irrigation water. Climate change will increase the risk of water deficits in most developing countries.

The impact from increased heat tolerance would be significant. A study of the potential for wheat cropping in Ethiopia's warmer environments showed that if wheat cultivars were available that could cope with a 2 °C higher minimum temperature (night temperature) the wheat production area on the periphery of the Ethiopian Highlands would potentially double. In multi-cropping systems, where wheat is rotated with cash crops (rice, cotton), delayed sowing of wheat can subject it to sub-optimal, often hotter growing seasons. In the rice-wheat system of eastern India, remote sensing studies have shown that at least 60% of the wheat area is planted late. Improving wheat's adaptation to high temperatures in these systems would considerably benefit subsistence farmers.

Why international agricultural research?

Through their role in the largest international wheat improvement network, the CIMMYT and ICARDA wheat programs have a long history of collaboration with researchers in national agricultural research and extension systems, agricultural research institutions, and private companies, and have established precedents in freely sharing international public goods. In recent consultations with national wheat program representatives from all major developing world wheat-growing regions, heat and drought stress were identified as the major yield-limiting priorities, reflecting long-term recognition of the disastrous effects of these constraints.

Through a combination of trait and molecular breeding and wide crosses, and collaborative efforts of an international phenotyping network, CIMMYT and ICARDA have improved the resistance of recently released advanced lines to a range of biotic and abiotic stresses; both institutions also house large collections of wheat genetic resources. Significant advances in gene discovery and in understanding genotype-by-environment interaction have been made through: development of precision phenotyping tools for a range of physiological traits; design of a new generation of experimental populations; innovative approaches in statistical analysis; and access to a vast database from international nurseries.

Researchable issues

A large body of recent work has demonstrated that new opportunities exist to improve the adaptation of wheat to heat and drought stressed environments (Trethowan and Mujeeb-Kazi 2008; Rebetzke et al. 2009; Reynolds et al. 2010). Conventional breeding with a special focus on adaptation to marginal environments provides a necessary baseline in terms of genetic backgrounds into which new traits and their genes can be introduced. However, specific research objectives to identify and accumulate new and appropriate combinations of stress-adaptive traits must follow a systematic approach, since there is still much to learn about how potentially useful traits (and their genes) interact—with each other, with different genetic backgrounds, and across the vast range of environments (including warmer and drier environments predicted by climate change) in which they must be deployed.

Outputs

1. New genetic materials based on combining useful expression of physiological traits whose additive gene action results in 15–30% better yield under heat and/or drought stress than that of current elite heat- and drought-adapted materials, with no significant yield penalties in favorable years, available by 2030.
    a. Phenotyping methods useful to the WHEAT community
    b. Molecular markers useful to the WHEAT community
2. Lines adapted to average temperatures approximately 2 °C above current temperatures in heat-susceptible environments.
3. Lines with roots that take up 95% of available moisture up to one meter below soil surface that, in combination with improved partitioning of biomass to yield, permit similar yields to be achieved with 15–20% less rainfall than currently experienced in drought-prone environments.
4. Wheat cultivars with enhanced stability of production despite unpredictable heat or drought stress.
5. Published information about yield limiting factors under heat and/or drought stress, and strategies for addressing these.

SI 6 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: New genetic materials with 15-30% higher yield under drought and/or heat by 2030.	**2***		**4**	**8, 9**	**12**	
Output 2: Lines adapted to +2°C average temperatures in heat-susceptible environments developed.	**2**		**4**	**8, 9**	**12**	
Output 3: Lines with roots that uptake 95% of available moisture down to 1m below soil surface.	**2**		**4**	**8, 9**	**12**	
Output 4: Wheat cultivars with enhanced stability of production despite heat or drought stress.	**2**		**4**	**8, 9**	**12, 14, 15**	
Output 5: Published information to inform SI6 strategies.	**1, 3**			**5, 6, 7, 8**	**10, 11, 13**	

*Refer to numbered milestone descriptions in the text

SI 6 Key Milestones

1.	Terms of reference determined for a quantitative framework of theoretical limits to yield under water-limited and heat-stressed environments.	*2011*
2.	Identification and sharing of primary genetic resources (with SI 9) likely to show favorable expression of physiological traits, prioritizing the following trait expressions: (1) deeper roots for dehydration avoidance; (2) stay-green as an indication of heat tolerance; (3) stability of reproductive processes under heat and drought stress; (4) buffering against unpredictable water supply at vulnerable growth stages; (5) adaptation to warmer night temperature; (6) heat tolerance without loss of water use efficiency; (7) tolerance to heat shocks; (8) adaptation to heat imposed on drought stress, and vice versa.	*2011*
3.	Identification of the most useful precision phenotyping tools (together with MAIZE) and definition of standard operating procedures and protocols, as well as of the need for further development/refinement and for molecular markers for "difficult-to-phenotype" traits.	*2011*
4.	Research networks established (with SI 10) that include environments with representative stress profiles that encompass the range of breeding targets, including "analog" environments that represent future climate scenario "hotspots".	*2013*
5.	Develop a quantitative framework of the theoretical limits to yield: (1) key stress factors and sensitive growth stages of wheat identified using genotype-by-environment analysis of all available trial data; (2) empirical data from other plant species surveyed and theoretical models to estimate the biological limits to heat and drought adaptation reviewed.	*2014*
6.	Environments characterized (together with Challenge Program CCAFS and SI 1) over successive cropping seasons to capture seasonal variation, and to define edaphic and crop management factors; climate predictions for regions identified until 2050.	*2014*
7.	Interactions of physiological traits (PT) with each other, with different genetic backgrounds, and across target environments documented in relation to their potential deployment in heat- and drought-stressed environments.	*2014*
8.	Develop precision phenotyping tools. Precision phenotyping tools developed and/or refined for application in breeding, genetic resource screening and gene discovery.	*2014*
9.	Experimental populations for QTL discovery developed, shared and phenotyped/genotyped.	*2014*

10.	Quantitative framework of theoretical limits to yield under water-limited and heat-stressed environments published, providing enhanced capacity to develop stress-adapted germplasm as well as to conduct both basic research and socioeconomic studies in relation to future climate scenarios.	*2015*
11.	Spatial data (distributions and frequencies of differentiated heat- and drought-stressed environments, vulnerable wheat farming populations, potential future heat- and drought-stressed environments) and analytical outputs made available in digital format, packaged with GIS software tools on CD-ROM.	*2015*
12.	Design of physiological trait combinations. First products of PT crosses containing complementary genes made available as genetic resources to national agricultural research and extension systems in order to quantify the effects of cumulative gene action on stress adaptation.	*2015*
13.	Conceptual models of physiological traits for major target environments updated, based on new information from genetic resource evaluation and thorough characterization of target environments.	*2015*
13.	First products of wide crossing (from SI 9) made available to international agricultural research centers and national agricultural research system breeders.	*2015*
14.	Putative molecular markers for “difficult-to-phenotype” traits made available for application (with SI 4) in marker-assisted selection.	*2015*

Outcomes

- Technologies, especially wheat lines, will be available for wheat researchers to increase yield stability despite the effects of climate change and unpredictable new combinations of heat and drought stress.

Targets and impact estimates

Farmers in food-insecure countries, as well as growers in major ”breadbaskets” worldwide, who are affected by heat and drought stresses and/or by anticipated negative impacts of climate change, with special focus on regions where farmers’ livelihoods are most vulnerable to climate change.

In six years there will be quantifiable genetic improvement of the key traits that are currently the major constraints to achieving heat and drought tolerance in wheat, and a 20% yield increase and first variety releases for drought and heat tolerance in 2020. We assume by 2030 we will cover 50% of the 20 million hectares in the Indo-Gangetic Plains with stress-tolerant varieties, with 60% of the yield gains transferring into farmers’ fields. In the dryland areas of CWANA we predict that we will cover 30% of the 24 million hectares by 2030.

Research and development partners

Collaborators will include WHEAT SIs 1, 2, 9 and 10, CIMMYT, ICARDA, CCAFS, GCP, agricultural research institutes (Australia, France, Germany, Italy, Spain, UK, USA), national agricultural research systems (Bangladesh, China, Egypt, India, Iran, Morocco, Nepal, Pakistan, Sudan), private sector seed companies, and nongovernmental organizations. Also, those national agricultural research systems that are working on heat and drought stress in wheat-growing areas (as above), prioritizing those in regions most likely to be affected by climate change.

Other issues

Gender

Long-term climate change poses a new set of challenges to farmers dependent on crop and natural resources. The adaptive capacity of people depends on how they can draw from resources to maximize their livelihood outcomes (Masika 2002). Thus adaptation depends on factors such as economic status, technology, health, education, information, skills, infrastructure, access to assets, and management capabilities—all impacts affected by WHEAT. Women have distinct vulnerability, exposure to risk, coping capacity and ability to recover from climate change impacts (Masika 2002) such as drought and heat. Although women are generally more vulnerable to the impacts of climate change, they play an active role in adapting to its impacts to secure food and a livelihood for their household.

Lessons learned

One area of concern, based on experiences from past projects, is unrealistic donor-imposed time expectations. Often, there is pressure on lead centers to start working on projects before all project partners are up-to-speed or able to begin efficient collaboration. There are often many unknown variables in large, multi-partner projects that can relate to human capital, infrastructure, politics, logistics regarding seed multiplication and movement, timing of globally distributed crops cycles, along with unpredictable environmental factors such as weather. In reality, we need at least two–three years (not a few months) to establish the kind of teams and conditions necessary to create a reliable research platform that can lead to results. This starts with identifying partners, training them where needed, checking on and complementing their facilities, and achieving an agenda that the whole team agrees on.

Research methods

- Identify and characterize wheat regions with a high density of resource-poor farmers affected by heat and drought stress. These environments are not well defined even now, and their characterization (taking into account future climatic scenarios) will permit more precise targeting of traits to current and anticipated stress profiles.
- Design physiological trait combinations to address heat- and drought-stress targets identified above. Based on present-day conditions, major target environments include the following stress scenarios: terminal heat and drought stress; continual heat stress with high and low relative humidity; a range of unpredictable environments where rainfall and temperature vary significantly within and between seasons. Examples of stress-adaptive physiological traits that have proven useful under

these conditions include: adjustment of development patterns so that sensitive crop stages avoid stress; deeper roots enabling plants to remain hydrated under drought and permitting canopy cooling under heat stress; increased transpiration efficiency so that scarce water is budgeted over the entire crop life cycle; delay of leaf senescence under heat stress; and stability of the reproductive processes to maintain harvest index under heat or drought stress. Crosses will be made among parental sources of physiological traits, to facilitate their deployment to target environments. However, there is still a lack of information on how these traits interact with each other, with different genetic backgrounds and across target environments. Therefore, an important part of this objective, dovetailing with others below, will be to quantify these interactions so that traits (and their genetic markers) may be more effectively deployed in breeding.

- Use wild relatives, landraces, and other genetic resources to augment the number of stress-adaptive mechanisms available for crossing—for when conventional germplasm sources lack adequate diversity in physiological trait expression. Although considerable diversity exists in genebank collections, to date relatively little has been utilized in breeding. There is an urgent need to identify sources of traits that permit cultivars to: (1) be buffered against unpredictable variation in water supply; (2) adapt to warmer nights without the unacceptable loss of assimilates that is associated with dark respiration; (3) experience high daytime temperatures without significant loss of water-use efficiency; (4) tolerate very sudden changes in temperature; (5) adapt to combinations of stress factors, such as heat imposed on drought stress.
- Form partnerships among wheat-breeding ***groups*** that face similar challenges to accelerate genetic gains through sharing of genetic resources and establishing networks of test sites (the latter effectively extends the “field laboratory” of all partners). For example, to achieve impacts in the face of climate change, so-called “analog” sites that currently represent the major target environments predicted to exist 10–20 years hence (the typical time frame of a breeding cycle) will be included at “hotspots” for field evaluation.
- Develop precision phenotyping tools to assist with the dissection of yield into its physiological trait and genetic components. These have clear application in breeding, gene discovery and screening of genetic resources, and aid in understanding both genotype and QTL-by-environment interactions. Because it relies on precise phenotyping, development of molecular markers for hard-to-phenotype traits (for eventual application in marker-assisted breeding) will be part of this objective.
- Develop a quantitative framework of the theoretical limits to yield under water-limited and heat-stressed environments to help establish realistic breeding and research targets for future climate scenarios (dovetailing with activities in CRP 7). This work would employ data from the activities described above (for example, to identify key stress factors and sensitive growth stages), empirical data from other plant species, and theoretical models to estimate the biological limits to heat and drought adaptation.

What's new in this initiative?

- A systematic approach to genetic improvement for heat and drought environments integrating conventional, physiological, molecular, and wide-cross approaches to breeding, as well as GIS to better define target sites.
- Use of "analog" environments to breed for future climate scenarios.
- International network of scientists focused on adapting wheat to climate-change-induced abiotic stress factors.
- Theoretical framework to establish probable limits to wheat yield under heat and drought stresses.'

SI 6 References

Braun, H.J., Atlin, G. and Payne, T. 2010. Multi-location testing as a tool to identify plant response to global climate change. In: Reynolds, C.R.P. (ed.), Climate Change and Crop Production, CABI, London, UK.

Masika, Rachel. 2002. Gender and climate change. *Gender and Development Journal* 10 (2): 2–9.

Rebetzke, G.J., Chapman, S.C., McIntyre, L., Richards, R.A., Condon, A.G., Watt, M. and Van Herwaarden, A. 2009. Grain yield improvement in water-limited environments. In: Carve, B.F. (ed.), Wheat: Science and Trade. Ames, Iowa, US, Wiley-Blackwell, 215–249.

Reynolds, C.R.P., Hays, D. and Chapman S. 2010. Breeding for adaptation to heat and drought stress. In: Reynolds, C.R.P., Climate Change and Crop Production, CABI, London, UK.

Trethowan, R.M. and Mujeeb-Kazi, A. 2008. Novel germplasm resources for improving environmental stress tolerance of hexaploid wheat. *Crop Science* 48, 1255-1265.

Table SI 6.1. Regional priorities of abiotic stresses for wheat production in developing countries by 2030.

Abiotic stress	East Asia **	South Asia	West-Asia	Middle East/North Africa	Central Asia/Caucasus	Sub-Saharan Africa	Latin America	Area where economically significant losses can occur	Developed countries
Dry/rainfed	+	+	+++	+++	++	+++	+++	50	++
Sub-optimal irrigation	+	++	++	++	++	-	+	35	0
Heat	+	+++	+	++	+	+	++	30	++
Cold	+	0	++	0	+	0	+	3	++
Acid soils	+	0	0	0	0	+	++	2	+
Saline/alkaline soils	0	+	++	+	++	0	0	7	+
Micronutrient disorders	+	+	++	+	+	+	+	20	+

** +++ = very important; ++ = important; += some local importance; 0 = not important.

Strategic Initiative 7. Breaking the yield barrier

Value proposition
A consortium of world experts in complementary research fields will harness recent advances in science to raise the genetic yield potential of wheat.

Estimated impact	2020	2030
Annual production increase	First variety releases.	9 million additional tons of wheat grain.
Benefit to the poor	All wheat growers in developing countries will benefit from higher and more stable yields. The urban poor will benefit from food security and affordable prices for wheat.	
Benefit to the environment	The pressure to bring natural ecosystems into cultivation will decrease; improved water- and nutrient-use efficiency in existing wheat systems will help to stabilize the natural resource base.	
Annual value addition		USD 2.160 billion.

Justification

General background
Global wheat production must increase at least 1.6% annually to meet a projected yearly wheat demand of 760 million tons by 2020. However, since the quantum leap of the Green Revolution, wheat yields have been rising by only 1.1% per year, a level that falls far short of the demand of a population that is growing 1.5% or more annually. This potential shortfall, if not addressed, could worsen due to climate change impacts on wheat, and could contribute to increases in food prices. Many approaches have been used to improve the wheat plant and raise its yield potential, but the fundamental obstacle—namely photosynthetic capacity—has hardly changed. This SI represents an effort by leading wheat research institutes worldwide to achieve another quantum leap in wheat productivity through parallel research in four areas/themes: (1) improving photosynthetic performance; (2) optimizing grain yield while improving lodging resistance; (3) breeding to accumulate yield potential traits; and (4) breeding high-yielding, cost-effective wheat hybrids. The Wheat Yield Consortium (WYC), first assembled in 2009, with a detailed business plan since elaborated.

Whole-genome (or genomic) selection is a new approach of molecular breeding that capitalizes on the continuous fall of genotyping costs and on the development of new statistical approaches predicting the performance of new lines from the entire genome information. It has potential to greatly increase genetic gains per time in elite x elite crosses.

Hybrid wheat, a promising approach for improving yield potential, yield stability and pyramided stress tolerances, should attract private-sector investment and accelerate breeding gains. However, until now large-scale production of hybrid wheat has been prevented by the difficulty encountered in developing reliable hybrid wheat-seed production systems, with demonstrated yield advantages.

The objectives of this SI are ambitious, but recent advances in science (see Long et al. 2006; Parry et al. 2010; Zhu et al. 2010) offer opportunities that compel WHEAT to invest in these high-potential-payoff pursuits.

Why international agricultural research?
In August 2008, work began on an initiative to double the current rate of breeding progress in wheat yield through a combination of advanced and conventional technologies. Linkages were established among laboratories worldwide that had the required physiological and genetic expertise, and a set of related research project proposals was developed. In November 2009, experts held a meeting to examine a cohesive project proposal that had evolved from a CIMMYT-commissioned external review. At this meeting, CIMMYT's role in coordinating the "Wheat Yield Consortium" was met with unanimous approval.

Situated at the hub of the largest international wheat improvement network, CIMMYT has a long history of collaboration with researchers in ICARDA, national agricultural research and extension systems, advanced research institutes, and private companies. It has established precedents in capacity building and in providing international public goods in the form of germplasm and crop management practices.

Integrated breeding approaches have combined trait-based and molecular breeding, wide crosses with genetic resources and in-depth analysis of international nursery data sets. These approaches have resulted in higher yielding germplasm with improved resistance/tolerance to a range of biotic and abiotic stresses, gene discovery, and enhanced understanding of genotype-by-environment interactions. Breeding programs worldwide have used this improved germplasm, and today more than 50% of all wheat grown has CIMMYT material in its pedigree (Lantican et al. 2005).

During 2010 CIMMYT initiated several public-private partnerships to explore two approaches for developing a functional wheat hybridization system using proprietary technologies. The approaches aim to overcome current seed production problems. Through CIMMYT's participation, the technology will be incorporated into germplasm adapted to developing-country environments.

Outputs

Extent of genetic variation for photosynthetic efficiency documented, and sources of improved efficiency identified:

- Sources of enhanced radiation-use efficiency (RUE) identified or developed based on improved efficiency of CO_2 fixation at either or both whole plant (canopy) and cellular (Rubisco) levels, and genetic markers and constructs developed where appropriate.
- Genetic variability for radiation-use efficiency known for elite wheat lines, landraces, and wild relatives.

Sources of improved spikelet fertility identified:

- Sources of improved expression of spikelet fertility identified.
- Physiological and genetic basis of spikelet fertility and its interaction with the environment better understood in all major wheat agro-ecosystems.
- Molecular markers for appropriate traits developed.

Lines combining yield potential enhancing traits with suitable lodging resistance:

- Lines with improved stem and root strength identified in lodging-provoking environments.
- Sources of improved lodging resistance combined with RUE and spike fertility using trait-based breeding or wide crossing, and outputs shared with breeders.
- Confirmation that whole-genome selection will provide genetic gains per time at least twice as high as conventional field breeding.
- Progeny from all breeding methodologies tested across a range of representative wheat target environments, with an emphasis on high-yield potential sites, in the developing world.
- Dissemination of genotypes that perform best to breeding programs worldwide.

Cost effective technologies to enable high-yielding hybrid wheat breeding:

- Wheat heterotic groups established and parental lines developed.
- Experimental hybrid systems developed that allow seed production at competitive prices with 15% higher yield.

SI 7 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: Sources of radiation-use efficiency identified or developed.	**1*, 2**	**5, 6, 7**	**9**	**10**	**8**	**11, 16, 17**
Output 2: Sources of improved expression of spikelet fertility identified.	**1, 2**	**5, 6, 7**	**9**	**12**	**8**	**16, 17**
Output 3: Lines combining yield-potential-enhancing traits with suitable stem lodging resistance.	**1, 2, 3, 4**	**5, 6, 7**	**9**	**12, 13**	**8, 14**	**16, 17**
Output 4: Cost effective technologies to enable high-yielding hybrid wheat breeding.	**1**				**15**	**16, 18, 19, 20**

*Refer to numbered milestone descriptions in the text

SI 7 Key Milestones

1.	A five-year research plan—and collaborative linkages—established for subprojects under the four main research themes.	*2011*
2.	Genetic resources identified (with SI 9) and assembled for likely useful expression of traits related to radiation-use efficiency.	*2011*
3.	Conceptual models of yield potential trait combinations developed for major agro-ecosystems, and initial crosses made based on conceptual models of yield potential traits using currently available genetic diversity.	*2011*
4.	Strategy implemented to test the value of whole-genome selection in wheat.	*2011*
5.	Core germplasm sets for main research objectives shared and trait expression measured where appropriate in major wheat agro-ecosystems.	*2012*
6.	Populations identified for molecular marker development of “hard-to-phenotype” traits.	*2012*
7.	Candidate traits identified for exploration among genetic resources and wide crosses.	*2012*
8.	Molecular markers identified for “hard-to-phenotype” traits.	*2013-16*
9.	Precision phenotyping protocols refined.	*2013-16*
10.	Sources identified for improved canopy photosynthesis (including spikes), Rubisco, and regulatory proteins such as Rubisco activase.	*2013-16*
11.	Genetic constructs ready for proof of concept—improved RuBP regeneration, Rubisco activase, and Rubisco subunits with enhanced catalytic properties, and genes from algae and cyanobacteria to concentrate CO_2 in the wheat chloroplast compartment where Rubisco is located, to eliminate photo-respiration.	*2013-16*
12.	Sources of improved expression of spike fertility identified based on both empirical observation and a better understanding of how environmental signals affect partitioning of assimilates to reproductive organs.	*2013-16*
13.	Sources of improved lodging resistance identified (with SI 9) based on improved stem and crown root strength.	*2013-16*

14.	Interactions and "trade-offs" between harvest index and lodging resistance better understood at the physiological and genetic levels and in terms of interaction with major wheat agro-ecosystems, resulting in refinement of the conceptual models for yield potential.	*2013-16*
15.	Source heterotic groups identified and assembled.	*2013-16*
16.	Progress within three major research themes reviewed and reported, and subsequent phase of research projects developed.	*2016*
17.	Core germplasm sets reviewed based on new information, and characteristics of major wheat agro-ecosystems redefined based on socioeconomic and climate change predictions, as well as analyses of genotype-by-environment interactions.	*2016*
18.	First products of enhanced yield potential germplasm yield tested in targeted wheat agro-ecosystems.	*2016*
19.	Whole-genome selection implemented where appropriate.	*2016*
20.	Field testing of experimental hybrids.	*2016*

Outcomes

- Wheat lines with novel high-yield-enabling traits are used by researchers.
- New wheat lines able to resist structural failure, thereby reducing losses in grain yield and quality.
- The use of whole-genome selection in wheat improvement programs increases due to technologies developed and validated by SI 7.
- Wheat lines with improved adaptation to warm environments (through reduced photorespiration and increased resilience of hybrid wheat) are used by researchers and farmers.

Impact estimates

Quantifiable genetic improvement of key traits that are currently the major constraints to increasing wheat yield potential will result in proof-of-concept in six years and first variety releases in the 2020s. The technologies will be adopted first in favorable areas such as China, Egypt and South Asia and will be aggressively promoted by the private sector. We expect that by 2030 a minimum of 15 million hectares of hybrid wheat will be grown in developing countries due in part to this program, with a 15% yield increase over a 4 ton per hectare average yield. Estimates of yield increases due to higher resource-use efficiency (15–50%) have a high range of possible variation and are hence not included in the impact estimates at this stage.

Other issues

Research methods[17]

- Approaches to increasing crop biomass through simultaneously: (1) modifying radiation use efficiency (Zhu X-G et al. 2010); (2) adapting reproductive processes to variation in seasonal and other environmental factors; (3) improving lodging resistance (Berry et al. 2007).
- Analysis of the photosynthetic performance of germplasm with demonstrated variation in Rubisco properties and associated regulatory proteins such as Rubisco activase; use of genetic manipulation to engineer RuBP regeneration and Rubisco activase, or to introduce Rubisco subunits with enhanced catalytic properties (Parry et al. 2007).
- Functional validation of two genes responsible for elevating CO_2 in algae and cyanobacteria; transfer of these genes to wheat chloroplast membranes to concentrate CO_2 in the compartment where Rubisco is located, thereby eliminating photo-respiration and ensuring Rubisco operates closer to its catalytic optimum (Price et al. 2008).
- Processes that increase the availability of assimilates to the developing spike, reduce early grain abortion, and improve spikelet fertility. These processes are affected by photosynthetic capacity and intra-plant competition between organs for assimilates (Reynolds et al. 2009). Interaction of these processes with photoperiod, temperature, and water and nutritional status.
- Adequate partitioning among grains, stems and roots to avoid structural failure using theoretical and empirical models; the models are based on the data generated with a broad range of genetic resources, grown in major wheat agro-ecosystems to establish their genetic basis and genotype-by-environment (G x E) interactions (Berry et al. 2007).
- Integration of physiological and molecular breeding methodologies and wide crosses into conventional approaches—including hybrid wheat—so that genetic gains in yield will occur in the context of other essential traits, such as disease resistance and end-use quality (cf. SI 4).
- Use of wide crosses to expand the wheat gene-pool in cases where conventional sources lack adequate genetic diversity (Trethowan and Mujeeb-Kazi 2008) for photosynthetic traits, spike fertility, lodging resistance and heat tolerance; use of wide crossing to generate additional lines that include all the chromatin required for full expression of C4 photosynthesis (Knowles et al. 2008).
- Development of cost-effective hybrid wheat systems using chemical hybridizing and/or GM systems. Establishing heterotic gene pools in wheat using genomic association analysis and selection.

[17] Further methodological details can be obtained upon request, referring to the Wheat Yield Consortium (2010).

What's new in this initiative?

1. The fundamental hindrance to increasing wheat yield potential is seriously being addressed, using a holistic approach that combines research focused on cellular and sub-cellular processes with genetic modification of structural and reproductive aspects of growth to ensure net agronomic benefits.
2. There is a new wheat research paradigm, where a consortium tackles a problem that is prioritized by a global group of stakeholders from both the developed and developing worlds. Unprecedented willingness of experts to share ideas within the consortium.
3. Public-private partnerships that bring together complementary assets and capabilities to develop a cost-effective hybrid system that benefits farmers in both developed and developing countries.

SI 7 References

Berry, P.M., Sylvester-Bradley, R. and Berry, S. 2007. Ideotype design for lodging-resistant wheat. *Euphytica* 154: 165–179.

Lantican, M.A., Dubin, H.J. and Morris, M.L. 2005. Impacts of International Wheat Breeding Research in the Developing World, 1988–2002. Mexico, DF: CIMMYT.

Long, S.P., X.G. Zhu, S.L. Naidu and D.R. Ort. 2006. Can improvement in photosynthesis increase crop yields? Plant Cell Env. 29:315-330.

Knowles, R.V., Walch, M.D., Minnerath, J.M., Bernacchi, C.J., Stec, A.O., Rines, H.W. and Phillips, R.W. 2008. Expression of C4 photosynthetic enzymes in oat-maize chromosome addition lines. *Maydica* 53: 69–78.

Parry, M.A.J., Madgwick, P.J., Carvalho, J.F.C. and Andralojc, P,J, 2007. Prospects for increasing photosynthesis by overcoming the limitations of Rubisco. *Journal of Agricultural Science* 145: 31–43.

Parry, M.A.J., M. Reynolds, M.E. Salvucci, C. Raines, P.J. Andralojc, X.G. Zhu, G.D. Price, A.G. Condon and R.T. Furbank. 2010. Raising yield potential of wheat. II. Increasing photosynthetic capacity and efficiency. J. Exp. Botany doi:10.1093/jxb/erq304

Price, G.D., Badger, M.R., Woodger, F.J. and Long, B.M. 2008. Advances in understanding the cyanobacterial CO_2-concentrating-mechanism (CCM): functional components, Ci transporters, diversity, genetic regulation and prospects for engineering into plants. *Journal of Experimental Botany* 59: 1441–1461.

Reynolds, C.R.P., Foulkes, J.M., Slafer, G.A., Berry, P., Parry, M.A.J., Snape, J. and Angus, W.J. 2009. Raising yield potential in wheat. *Journal of Experimental Botany* 60: 1899–1918.

Trethowan, R. and Mujeeb-Kazi, A. 2008. Novel germplasm resources for improving environmental stress tolerance of hexaploid wheat. *Crop Science* 48: 1255–1265.

Zhu, X-G, Long, S.P. and Ort, D.R. 2010. Improving photosynthetic efficiency for great yield. *Annual Review of Plant Biology* 61: 235–261.

Strategic Initiative 8. More and better seed

Value proposition

Enhance the ability of wheat-producing countries to build more diverse and sustainable seed systems that offer farmers better access to and choices of improved varieties through broader participation of the public and private sectors as well as alternative and innovative seed production and marketing by farmer groups/communities.

Justification

General background

"Improved varieties in farmers' fields" is one of the most important outcomes of breeding efforts by NARSs and international centers. If seeds of these varieties do not reach farmers, a major intervention point to increase wheat productivity and to take farmers out of poverty is missed. And yet, most seed systems in developing countries are limited by ineffective policy and regulatory frameworks, inadequate institutional and organizational arrangements, and deficiencies in production infrastructure, compounded by farmers' difficult socioeconomic circumstances (Table 8.1). The performance of these systems, regardless of the crops involved, depends on a combination of factors that range from scientific advances in the development of well-adapted varieties to the creation of effective seed markets that reach the majority of farmers.

In contrast with seed production for hybrid crops, the wheat seed sector depends heavily on public organizations whose technical capacity, and market orientation often are inadequate. Such weaknesses may seriously hinder farmers' access to seed of new wheat varieties. In some major wheat-producing countries the formal sector (including both public and private companies) meets, on average, less than 10% of the wheat seed requirement—ranging from 4% in Ethiopia to 14% in Pakistan.

Annually about 108 million hectares are planted to wheat in the developing world of Eastern Africa, Middle East/North Africa, Central Asia and Caucasus, South and East Asia. To this area can be added other developing regions like South America, where there are 9.1 million hectares of wheat. The majority of these developing countries have reported weak wheat-seed systems as the main impediment for technology uptake and adoption. For example, despite eminent danger from devastating diseases, such as the Ug99 race of wheat stem rust, farmers in many developing countries continue to grow obsolete, susceptible varieties, creating serious risks to global food security. In India and Pakistan alone, close to 14 million hectares are planted with two varieties released during the 1990s (including 7 million hectares sown to PBW343 in India, and 6.5 million to Inquilab 91 in Pakistan) because of low varietal replacement rates. Limited availability and use of seed of well-adapted varieties that farmers prefer pose major constraints. More flexible mechanisms for fast-track variety release, coupled with stronger promotion and accelerated multiplication of seed of new wheat varieties, are critical for quicker varietal replacement in farmers' fields.

To improve national seed systems, favorable policy, regulatory and business frameworks are critical for broadening the participation of the private sector in accordance with current trends in the global seed industry. In addition, capacity must be improved to strengthen the public and emerging private sectors, including farmer-based seed production and marketing units to enhance the availability, access and use of seed of new wheat varieties at the farm level.

Why international agricultural research?

Improved varieties are a well-defined output of research, and seeds are the key means of delivering them. The international agricultural research centers and their national partners need to forge new partnerships with the public and private sectors to find more effective means of delivering improved products to farmers. CIMMYT and ICARDA are linked to an extensive seed-related network of international organizations/associations. These include the Food and Agriculture Organization (FAO), Organization for Economic Cooperation and Development (OECD), International Seed Testing Association (ISTA), International Seed Federation (ISF), and International Union for Protection of New Plant Varieties (UPOV). Other links are with regional agricultural research organizations such as ARINENA, CACARI, ASARECA, and APARI; regional seed trade associations such as AFSTA, APSA, etc., also regional seed initiatives such as AGRA and both multinational and local private seed companies. The global seed industry's wealth of information, experience, and expertise is vital for enabling wheat-producing countries to develop more robust national seed systems.

Researchable issues

Seed is both a technology and a means of delivering technology. The enhancement of seed systems requires research (together with SI 1 and 2) on a wide range of issues, including: advocacy for policies that stimulate private-sector participation, including profitability analyses; rationalization and harmonization of regulatory frameworks to create regional seed markets; liberalization and commercialization of the public seed sector to create a more competitive seed market; intellectual property rights on plant varieties to encourage investment; strengthening of capacity for seed production and marketing for maintenance of seed quality (with adequate equipment and facilities) and for human resource development to provide effective leadership in enterprise development and management; and public-private sector partnerships for seed research and delivery. The following are specific issues that must be addressed in order to develop competitive seed industries that respond to farmers' needs:

1. *Comparative analysis of the performance of the seed sector across countries, using standard criteria that critically evaluate and address technical, organizational, institutional, regulatory, and policy matters.* The needs of each country will be assessed, resulting in wheat-seed sector profiles and the identification of gaps; on this basis, bilateral or multilateral projects will be formulated to address country-specific issues and strengthen national institutions.
2. *Advocacy for sound, flexible government policies that promote private sector participation as well as innovative farmer-based seed supplies, particularly in dry areas.* Past policies have given rise to an

inefficient seed sector in which public institutions dominant, local private companies are marginalized, and the operations of international seed companies are suboptimal. Removing these obstacles to progress in the seed sector requires a critical analysis of current policies and more informed decisions by national governments.

3. *Improved national seed regulatory frameworks for variety release, seed certification, and phytosanitary measures.* Current frameworks must be rationalized (nationally) and harmonized (regionally) in keeping with international conventions, to facilitate cross-border seed trade, create regional markets, and attract both domestic and foreign investment. Thorough reform must be preceded by a comprehensive analysis involving a consultative process. Model regulatory frameworks can be adapted to countries and regions with similar conditions or economic blocs.
4. *Streamlined procedures to ensure faster seed multiplication and better access to seed to foster dissemination of new varieties.* Currently, there is a long time lag between varietal release and the production of sufficient quantities of basic seed for large-scale multiplication, due to poorly functioning breeder-seed units and seed-delivery systems in the public sector. To remedy this constraint requires a thorough review of variety maintenance and breeder-seed production and the formulation of appropriate measures.
5. *Better availability, access, and use of high-quality wheat seed.* In many major wheat-growing countries of the developing world, certified seed covers on average about 10% of the seed replacement rate because of limited capacity and lack of investment in the seed sector. The volume of readily available certified seed must be increased to at least 25% of the seed replacement rate in order to raise wheat productivity.
6. *Design technically feasible and economically sustainable farmer-based seed production and marketing enterprises, which can be scaled out in dry wheat-growing areas of the developing world.* Since the formal seed sector tends to perform poorly in those areas, particularly in servicing small-scale farmers, it is important to mobilize, organize, and support the farmers themselves for producing and marketing quality seed within their communities and beyond (complementing activities and approaches used in SI 2). This is particularly necessary where participatory variety selection is used to complement and extend formal breeding programs. Research on alternative seed delivery can build on the local institutions and on the knowledge, skills and experience of farming communities—particularly women.
7. *Options for diversifying the wheat seed sector and making it more competitive.* Even in countries with liberalized seed sectors, these tend to be dominated by the public sector, while private sector participation is minimal, resulting in inefficient wheat seed production and marketing systems. Research on seed marketing is needed to measure the competitiveness of public- and private-sector producers and to formulate options for government intervention aimed at diversifying suppliers. Such research should also create a better understanding of the determinants of seed supply and demand, as well as new insights into farmers' choices about wheat varieties and seeds, which could facilitate seed marketing. The support of seed dealers' networks and national seed associations should also help.

8. *Capacity development in national seed programs.* Strengthened human resources are critical for the diversification of national seed industries, with emphasis on technical issues and business/ financial management for seed enterprise development—both formal and farmer-based enterprises.
9. *Ensuring seed security in times of disasters.* Wheat growing areas may face natural disasters (sudden outbreak of diseases, etc.) and dry areas are particularly prone to frequent drought and seasonal climatic variability. All these factors affect the availability of seed for planting under emergency conditions. National seed security frameworks need to be established in the form of grain-for-seed, security stock, etc., to address the problem. Guidelines will also be developed for fast track variety release and accelerated seed multiplication for emergency situations, such as Ug99.

SI 8 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: Comparative assessments of the status of the wheat seed sector. (with SI 1)	**1***	**1**				
Output 2: More flexible national systems for more rapid variety release.		**3**				
Output 3: More functional seed units for variety maintenance and early generation seed multiplication.			**5**			
Output 4: Improved infrastructure and equipment for national seed systems.		**3, 4**				
Output 5: Better access to high-quality, certified seed of improved wheat varieties.						**7**
Output 6: Analyses of the technical efficiency of public- and private-sector seed producers. (with SI 1)			**5**			
Output 7: Alternative seed delivery systems, i.e., farmer-based seed production and marketing units.		**3**				
Output 8: Capacity of public and private seed sector institutions enhanced and personnel trained.	**2**	**2**	**2**	**2**	**2**	**2**
Output 9: Enabling seed policies, based on thorough analysis of current arrangements.	**1**	**1**				
Output 10: Recommendations for national seed regulatory frameworks.	**2**	**2**	**2**	**2**	**2**	**2**
Output 11: Framework for national seed security in vulnerable regions.	**1, 2**	**1, 2**	**2, 5**	**2**	**2, 6**	**2**

*Refer to numbered milestone descriptions in the text

SI 8 Key Milestones

1.	Analysis of national seed systems (with SI 1) completed in at least 10 countries and recommendations made to national governments.	*2011-2012*
2.	Functional variety maintenance and breeder seed units and procedures established (with SI 4) in at least five target countries (one per year).	*2011–16*
3.	Five farmer-based seed production and marketing enterprises established in at least five countries.	*2012*
4.	Review of needed equipment completed in at least five countries.	*2012*
5.	National studies on the technical efficiency of public- and private-sector wheat seed production completed (with SI 1) in at least five countries.	*2013*
6.	National seed policies developed and adopted in at least five target countries that have weak wheat seed systems.	*2015*
7.	At least 10% of the cultivated wheat area sown to newly released varieties provided by the formal seed sector, reaching a minimum target of 25% of wheat seed in selected countries.	*2016*

Outcomes

- Harmonized regulatory frameworks for seed industry allow exchange of crop varieties and seeds within regions or across borders, and regional seed associations to create regional seed markets.
- Improved policy and regulatory frameworks facilitate the establishment of seed enterprises.
- Functioning seed systems attract private sector investments.
- Improved availability of, access to, and use of quality seed by farmers.
- Seed security framework established for vulnerable regions.

Targets and estimated impacts

Seed system analysis and research will be conducted through a holistic approach that targets countries with weak seed systems in different regions and sub-regions where wheat is a major crop. Selected countries with varying levels of wheat seed systems development (developing to least developed) will be included, enabling researchers to derive lessons from their experience for the benefit of countries with less developed seed industries. The target countries may include Afghanistan, Algeria, Egypt, Ethiopia, Iran, Kazakhstan, Morocco, Pakistan, Syria and Turkey in the CWANA region, and Bangladesh, Nepal, India and others in South Asia.

Gains projected in SIs 4 and 5 are based on effective seed production and distribution systems. Estimated impacts for this SI will therefore be realized through SIs 4 and 5.

Other issues

Gender

Women were probably the first to recognize the value of seeds as planting material. Since then, they have remained the guardians of seeds and played a central role in agricultural development. The traditional role of women as seed selectors and preservers is widely recognized and is partly explained in terms of their innate skills in observation, patience, organization, and concentration. The local seed system analysis provided highlights of gender roles in on-farm seed production and management. These attributes place women in key positions for participatory variety selection and seed production. NARSs are encouraged to engage women in farmer-research groups to harness their knowledge and involve them in evaluation of varieties, also in decision-making processes that will facilitate adoption of new improved wheat varieties.

In most rural communities, women participate extensively in crop production and agricultural wage labor. In some developing countries a significant proportion of female-headed households are also engaged in agricultural production. Despite their significant role women are confronted with constraints such as lack of access to land, capital, credit, information and other resources, thus limiting their adoption of new wheat technologies. Special efforts will be made to identify and work with local government offices, farmer/women groups, NGOs and donors to promote and foster the role of women in agriculture and rural development. Taking into consideration local cultural values, a gender-focused extension system will be designed to reach women farmers. The women will also be assisted to create linkages with rural credit services, negotiated on better and more favorable terms to overcome factors preventing them from easy access to information and resources for adoption of improved wheat technologies.

Women have been found to be better private dealers and commission agents—in formal seed trade and also as owners of local seed enterprises. They demonstrate greater responsibility in the management of their businesses than men. Therefore, women wheat farmers will be specifically targeted through project-based interventions to facilitate access to new wheat seed, and women entrepreneurs will be encouraged to form alternative farmer-based seed production and marketing schemes envisaged within the seed initiative. This will utilize their skills and knowledge in entrepreneurship.

These enterprises will be established, owned, and operated by women farmers with several advantages, including farmer participation or empowerment, decentralized seed production, business-orientation, cost effectiveness, and access to appropriate technology with focus on enterprise sustainability. Women entrepreneurs will be identified, organized, trained in technical aspects of seed production, and financial and enterprise management. These enterprises will be provided with basic facilities and possibly revolving operational funds. They will be legalized and linked to formal sector institutions with access to services and support.

Women farmers have knowledge of specific wheat quality traits for end-use products, made apparent from the value added to wheat in on-farm processing of wheat for traditional food products—a job mainly done by women. For example in the WANA region, durum wheat and in some cases bread wheat is processed into bread, pasta, couscous, *burghul,* and *frike*. These products contribute significant value addition and income generation for rural communities, where the women are key players. The organization and support of women producer groups to engage in on-farm processing and marketing of these products will improve the livelihoods of farm households. New improved varieties with good end-use quality traits for such traditional products would greatly benefit women farmers.

Developmental interventions

Developing sustainable wheat-seed delivery involves conducting research and seeking solutions. Therefore, within the research-for-development continuum, the work on improving the wheat seed sector will focus around specific research components that: address system constraints; facilitate technology transfer; and assist technology adoption and diffusion. Given the strong interface between variety development and seed supply, SI 8 may work closely and serve as a conduit for all of the WHEAT SIs that lead to the generation of new improved varieties and associated technologies, and with SI 1 to target institutional innovations.

Researchers will endeavour to develop public-private partnerships where public-bred varieties are equally accessed and commercialized—not only by the public sector but also by the emerging private sector. Apart from research issues, technical and material support is envisaged for critical infrastructure (such as equipment for early generation seed production at research centers, seed processing/testing equipment, seed storage facilities, etc.) for improving the capacity of the existing public sector, the emerging private sector, and local farmer-based enterprises. The major developmental work of seed delivery in terms of formal seed production and marketing, except for early generation seed, will be handled by the partnering public and private sectors. The center’s role will be limited to key facilitation and technical backstopping.

On the other hand, small-scale subsistence farmers living in less favorable dry areas and remote regions, who depend directly on farming for their livelihoods, did not benefit from agricultural research and investment due to the lack of effective technology transfer and poor seed delivery systems. At present, neither the public sector nor the private sector is able to serve these farmers effectively. Centralized production and marketing, compounded with poor accessibility, has led to high transaction costs. Hence, there is a need for direct project-based intervention to develop flexible alternative seed delivery through farmer-based seed production and marketing units that are “owned” and managed by farmers (Bishaw and van Gastel 2008; Srinivas et al. 2010).

These initiatives need to be: (1) *participatory*—mobilize and involve small farmers in target environments; (2) *decentralized*—multiply locally adapted and farmer preferred varieties; (3) *business-oriented*—link seed production to demand from communities; (4) *cost effective*—minimize transaction costs, thus reducing seed prices; (4) *of relevant quality*—adopt seed quality appropriate to farmer requirements; (5) *technology savvy*—use low-cost mobile seed cleaners/treaters to improve seed quality; and (6) *sustainable*—empower farmers to take leadership in seed business.

Farmers groups will be identified, organized, trained, registered and provided with varieties, seeds and facilities to initiate seed business. Farmers involved in these units will be: (1) responsible for seed production and marketing, but monitored and evaluated for their sustainability and (2) linked to key formal sector institutions for technical and financial support, as deemed necessary. The decentralized local-level seed production will substantially reduce transaction costs and will cater to local demand, as compared to highly centralized large-scale operations by the formal public and/or private sectors that work best helping easily accessible areas.

ICARDA has supported a regional seed network that has developed, published and distributed several technical publications on seed science and technology to fill information gaps in national seed programs. It continues supporting web-based information, where it shares CWANA publications like the *Variety Catalogue and Field and Seed Catalogue,* its regional seed newsletter *Seed Info* (published twice a year) and its supplement *Focus on Seed Programs*. A special effort will be made to update some of these regional documents, and to make them and national seed-sector studies available online.

Lessons learned

In most developing countries, the wheat sector remains in public domain in terms of agricultural research and seed delivery. Most CGIAR centers work directly with NARSs and the public seed sector. Despite their limitations, they continue to be the sole conduit to deliver new wheat varieties from research into farmers' hands. Past efforts to strengthen public agricultural research and seed delivery along the "seed chain" remained limited and focused on the seed supply side, lacking market orientation. Inherently weak institutional linkages along the chain, where variety development, seed production, seed marketing, and seed extension are handled by different, and sometimes independent institutions, become an impediment for progress.

In industrialized countries, the success of the seed industry has often resulted from integration of agricultural research, production technology, input supply, market support, and extension information driven by the private sector. For example, private seed companies (multinational or domestic) tend to reduce transaction costs through vertical integration of a research-seed/production-seed distribution continuum to recoup their investments (Morris, 2002). These realities call for a paradigm shift in seed sector development that favors liberalization, deregulation,and diversification to promote the emergence of a competitive seed industry that aims to satisfy the needs of a broad range of farmers.

The future approach for seed sector development, in addition to rationalization and advocacy for policy and regulatory reforms, will also focus on the market-orientation of the public sector to become competitive. There will be encouragement for private seed company participation and promotion of decentralized, farmer-based seed production and marketing units to reach small-scale farmers. From the outset, efforts will be made to work with a wide range of partners from national and international agricultural research centers, national seed sector development programs, agricultural development agencies, NGOs and donors—through a multi-stakeholder process to define their roles and commitments for implementing the strategic initiative.

Research methods

The status of national seed systems in the developing world is the manifestation of the politico-socioeconomic development path followed by each country. Thus, the national seed systems reveal variation in terms of policy, regulatory, institutional and technical arrangements in each country, and none can claim to have a fully functioning formal seed sector. The seed sector development can be broadly classified into three categories: (1) developing seed industries; (2) intermediate seed industries; and (3) least developed seed industries.

The first group, although deficient in some aspects, has a relatively functioning infrastructure with some pronouncements of national seed policy and regulatory frameworks. It has independent variety release and seed certification agencies and some private sector participation. Egypt and Pakistan fall into this category. In *the second group*, most countries lack clear seed policy and regulatory frameworks, lack independence, or have weak variety release and certification agencies. Most seed activities are handled by the public sector, where efforts to reform and/or diversify the seed sector are rather limited. *The third group* is characterized by countries where agricultural departments within the Ministry of Agriculture organize the seed sector on an *ad hoc* basis. Such countries not only lack policy and regulatory frameworks, they also lack institutions and infrastructure to support the development of an efficient seed sector.

The research methodology combines both comparative analytical studies across countries as well as specific country studies along the “seed chain” to assess the functioning of the wheat-seed system to derive successful models with potential spillovers for adaptation to specific country situations. The variation in seed-sector development among countries will provide a huge wealth of information for comparative analysis of the wheat-seed sector in selected developing countries, where lessons learned could be used to design better seed delivery options. A number of case studies would be employed to target some countries where policy reforms have made tremendous impact through private sector participation, particularly on wheat-seed delivery (e.g. in Pakistan, but not in Turkey). In addition, case studies will be conducted on the efficiency of seed production and marketing in countries where the public sector continues to dominate the wheat seed sector (e.g. Ethiopia) to identify critical bottlenecks for improvement. Furthermore, the functioning of the informal seed sector in terms of seed sources, seed acquisition, and seed management will be studied to design alternative seed production and marketing units and assess their sustainability.

The national seed polices, seed regulations, and country studies that are developed will be used by governments, national and international organizations, seed regulatory bodies, development agencies, and donors to improve the wheat seed delivery systems.

Developing a sustainable wheat seed delivery system is linked to plant breeding activities, because of the main objectives is to conduct research and seek solutions to wheat seed provisions. The primary focus of SI 8 is taking research outputs in the form of new varieties and associated technologies from other SIs and delivering them to farmers by improving seed delivery systems.

Quantified impact pathways

Modern crop varieties are well-defined outputs of collaborative research with national partners and they are a key means of delivering technology and realizing the benefits of investment in agricultural research. The comparative analysis of seed systems and country-specific studies conducted under this initiative will improve our understanding of constraints and results for proposed reforms in policy and regulatory frameworks, as well as improvements in the technical performance of the wheat seed sector. Those reforms or changes, in turn, will create an enabling environment for the development of competitive national seed industries with better performance in delivering seed to diverse groups of farmers.

The outcome should be a mix of government/public seed companies, foreign/domestic private seed companies, small seed enterprises, cooperatives/farmers associations, NGOs, and individual producers involved in seed production to meet the diverse needs of farmers. This will ensure better availability of, access to, and use of seed of improved wheat varieties by farmers, resulting in increased wheat productivity and production, which will ensure food security and improved livelihoods. As a result of this work, a better wheat-seed delivery system will be achieved and an estimated 10% of the wheat area in target countries will be planted to newly released varieties. This will bring about an incremental increase of 25% in seed replacement, facilitating variety adoption. If 10% of 108 million hectares in target developing countries with an average yield of 2.8 tons per hectare is planted with new wheat varieties with incremental yield advantage of 1.1% (0.28 tons), as in the past decades, it will produce approximately 3,240,000 additional tons, generating a substantial return on investment.

Research for development partners

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

- National agricultural research organizations working on variety development with international centers.
- National agricultural extension systems working with national partners in promoting improved wheat varieties and associated technologies.

- National seed regulatory agencies dealing with crop varieties, seeds, and phytosanitary measures IPRs, etc.
- Public sector organizations and emerging local, private-sector companies involved in wheat seed production and marketing.
- Regional and national seed trade associations representing the interests of the seed industry in their respective regions and countries.
- International partners, such as FAO, OECD, ISTA, ISF and UPOV, and NGOs with an interest in agricultural and seed-sector development.
- National agro-industries involved in wheat processing and marketing.

What's new in this initiative?

- Emphasis on market orientation of the public seed sector.
- Promotion of the private sector in seed delivery.
- Promotion of farmer-based seed production and marketing units.
- Rationalization (national) and harmonization (sub-regional or regional) of policy and regulatory framework to create regional market.

SI 8 References

Bishaw, Z. and van Gastel, A.J.G. 2008. ICARDA's approach to seed delivery in less favorable areas through village-based seed enterprises: conceptual and organizational issues. *Journal of New Seeds* 9 (1): 68–88.

Morris, M.L. 2002. The development of the seed industry under globalization. In: Bigman, D. (ed.), Globalization and the Developing Countries: Emerging Strategies for Rural Development and Poverty Alleviation, CABI/ISNAR, UK and The Netherlands.

Srinivas, Tavva, Bishaw, Zewdie, Rizvi, Javed, Niane, Abdoul Aziz, Manan, Abdul Rahman and Amegbeto, Koffi 2010. ICARDA's approach in seed delivery: technical performance and sustainability of village-based seed enterprises in Afghanistan. *Journal of New Seeds* 11 (2): 138–163.

Table SI 8.1. Ratings* of the seed sector in selected developing countries in Eastern Africa, Middle East/North Africa, Central Asia and Caucasus, and South and East Asia.

Countries	Wheat area	Variety testing	Breeder seed production	Variety release	Basic seed production	Certified seed production	Seed policy	Seed legislation	Regional harmonization	National seed service	Private seed companies	Public seed companies	Agricultural extension	Farmer association
Afghanistan	2,190,000	3	4	3	4	4	yes	yes	yes	5	4	5	5	5
Algeria	2,000,000	2	2	2	2	2	yes	yes	no	2	3	2	4	4
Armenia	113,300	4	3	3	3	4	no	yes	no	3	3	2	2	3
Azerbaijan	486,990	2	2	2	2	2	no	yes	no	3	3	4	3	4
Bangladesh	372,000	3	3	2	3	4	yes	yes	no	4	5	5	5	5
China	23,000,000	2	2	1	1	2	yes	yes	yes	3	4	4	3	4
Egypt	1,139,000	1	1	1	1	1	yes	yes	no	1	3	1	3	3
Ethiopia	1,351,000	2	3	1	4	4	yes	yes	no	5	5	4	2	2
Georgia	61,000	4	4	5	4	5	no	yes	no	5	3	no	5	3
India	28,035,000	2	2	2	2	3	yes	yes	yes	3	3	3	3	4
Iran	6,400,000	3	3	3	2	2	no	yes	yes	2	3	2	3	2
Iraq	2,750,000	5	5	5	5	5	yes	no	no	5	5	5	5	5
Jordan	30,000	4	2	2	3	4	no	no	no	2	4	5	5	5
Kazakhstan	12,876,700	1	2	1	2	1	yes	yes	yes	2	2	2	2	2
Kenya	150,000	2	2	2	2	2	yes	yes	no	3	2	2	3	3
Kyrgyzstan	354,500	1	3	1	3	2	no	yes	yes	3	3	3	3	4
Lebanon	48,000	3	3	3	3	3	no	yes	no	3	2	3	4	3
Libya	132,000	5	5	5	5	4	no	no	no	5	5	5	5	5
Morocco	3,000,000	1	2	2	1	1	yes	yes	yes	1	2	1	5	2
Nepal	702,664	3	3	2	3	4	yes	yes	no	4	5	5	5	5
Oman	275	3	3	2	2	5	no	no	yes	3	no	no	3	5
Pakistan	8,494,000	2	3	1	4	3	yes	yes	no	3	1	3	4	2
Saudi Arabia	462,000	3	5	5	2	2	yes	no	no	5	2	no	4	4
Sudan	250,000	2	2	1	2	4	no	yes	no	4	3	5	4	4
Syria	1,850,000	1	1	1	1	1	no	no	no	1	4	1	2	2
Tajikistan	330,000	1	3	1	3	2	no	yes	yes	3	3	3	3	3
Tunisia	856,000	1	1	1	1	1	yes	yes	no	3	4	1	4	2
Turkey	8,600,000	1	1	1	2	2	yes	yes	yes	2	2	3	3	3
Uzbekistan	1,400,000	1	2	1	2	1	yes	yes	yes	2	3	1	2	3
Yemen	114,030	2	1	1	2	3	no	yes	no	3	5	2	3	3
Total	107,548,459													

*Ratings: Strong (1) to very weak (5) based on general feedback of wheat researchers and development staff.

Strategic Initiative 9. Seeds of discovery

Value proposition

Leveraging top-end genomic and phenotypic technologies, to uncover the genetic heritage of wheat genetic resources held by CIMMYT and ICARDA and to build a platform that assists wheat researchers and breeders globally in targeted mobilization of novel diversity into breeding programs via well-characterized accessions and parental germplasm, wheat improvement will become more efficient and effective.

Justification

General background

Wheat[18] genetic diversity has been assembled and conserved over many decades in seed collections like those held by CIMMYT and ICARDA. This diversity has furnished the building blocks for breeding for modern, improved cultivars. However, only a small fraction of the vast genetic diversity of wheat 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 new marker and next-generation sequencing technologies. Breeders are yearning 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 SI will comprehensively address these constraints and thus assist breeders in the identification and targeted mobilization of useful diversity in wheat breeding programs worldwide.

Why international agricultural research?

CIMMYT and ICARDA collectively hold[19] the world's largest and most diverse collection of wheat diversity—comprising roughly 200,000 bread and durum wheats, modern rye and triticale varieties, landraces, genetic stocks, wild relatives and ancestral progenitors. These collections also serve as intermediaries between “upstream” basic and strategic research and “downstream” applied wheat breeding. The ex situ collections are directly linked to world-class plant breeders, agronomists, molecular biologists, socio-economists, and global partners that 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 state of research

The breadth of diversity in the Triticeae tribe raises many opportunities to introduce useful genetic variation for wheat improvement. Introgressions from wild wheat relatives have been important sources of genetic variation since the inception of CIMMYT’s wheat program; *Sr2*, *1B/1R* and *Lr19* are three

[18] Throughout this document, ‘wheat’ refers collectively to cultivated and wild *Triticum* spp., *Secale* spp., *Triticosecale* spp. and related primary (including *Aegilops* spp.) and secondary wild-relative genepools.

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

notable examples with major impacts in developing world agriculture. The over 1,000 synthetic hexaploid wheats resynthesized from progenitor species at CIMMYT and ICARDA have been a rich source for new variation for resistance or tolerance to a range of diseases and abiotic stresses (Ogbonnaya et al. 2008; Trethowan and Mujeeb-KazI 2008; Reynolds et al. 2009). The recent screening of landraces, primitive wheat, wild *Triticum* and *Aegilops* species to Ug99 virulent races and *Yr27* showed large number of potential sources of resistance that can be used to avoid significant yield losses due to these major wheat diseases.

The temporal and spatial diversity in elite wheat germplasm and wild relatives has been extensively analyzed with AFLP, SSR, and DArT markers (Medini et al. 2003; Warburton et al. 2006; Dreisigacker et al. 2008). A GCP-supported project involving CIMMYT, ICARDA, INRA, and CAAS, for example, allowed the definition of core collections for bread and durum wheat by characterizing 2,506 *Triticum* accessions with 50 SSR markers and using the strategy developed by Franco et al. (2005). DArT fingerprinting of international nurseries in combination with trait analyses has led to the first association-mapping and genomic-prediction studies in wheat (Crossa et al. 2007, 2010).

The Focused Identification of Germplasm Strategy (FIGS), currently being developed and used at ICARDA, employs information about the environment from which genebank accessions were collected to predict in-situ selection pressures and thus adaptive traits. Coupled with FIGS, EcoTILLING offers a powerful means of screening large germplasm collections for allelic variations and, more importantly, possible variation in gene expression (Keller et al. 2008).

Researchable issues

- Comprehensively characterizing the genetic richness of wheat in relation to its geospatial and adaptive distribution, including the identification of gaps in collections to fill with traits-targeted collecting missions.
- Exploring the phenotypic diversity of wheat in trait-dependent dynamic subsets assembled by a combination of FIGS, molecular diversity and other approaches/criteria.
- Identifying, by association mapping, novel and potentially useful genes including their alleles and allele combinations, also selecting donors for yield potential and abiotic and biotic stress tolerance and nutritional quality traits.
- Identifying selection imprints or allele-frequency clines across environmental gradients.
- Understanding the genetic control of traits and trait combinations, and a concurrent development of selection tools for breeding programs.
- 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 on basic knowledge required for wheat breeding, while encouraging 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 in an integrated manner the trait, molecular and geo-referenced passport data across the entire set of accessions.

- Mobilizing novel diversity into breeding programs via: (1) a pre-breeding pipeline that assists wheat breeders in the mobilization of novel alleles and (alien) genome segments into their breeding programs; and (2) strengthening/refining existing seed-conservation and delivery operations.

SI 9 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2016
Output 1: New accessions from collecting missions integrated into genebank holdings responding to gap analysis.	**1***					
Output 2: Phenotypic and molecular descriptions of conserved wheat diversity integrated with geo-referenced data via the WHEAT Diversity Portal.			**4**		**6**	**7**
Output 3: Repository available as a Global Public Good.		**2**				
Output 4: Data-mining results identify accessions carrying desirable traits made available via the Wheat Diversity Portal.		**2**	**4**	**5**	**6**	**7**
Output 5: Wheat Diversity Portal cross-linked with other wheat and IP-related internet resources to facilitate queries.		**2**				
Output 6: Seed from global wheat collections is made more easily accessible to wheat researchers, breeders and farmers worldwide.	**1**	**2**				
Output 7: New germplasm added to fill critical ecological, national, and user-defined gaps in collection.	**1**			**5**		
Output 8: CIMMYT and ICARDA-held wheat collections integrated into IT-facilitated global networks.		**2, 3**				
Output 9: Accession subsets assembled and made available to users.		**2**				
Output 10: New parental stocks and synthetics made available via a marker-assisted pre-breeding pipeline.	**1**	**2**		**5**		**7**

*Refer to numbered milestone descriptions in the text

SI 9 Key Milestones

1.	Business plan and terms of engagement of R&D partners developed.	*2011*
2.	Wheat Phenotyping Networks formed; priority traits, methods, research partners and accessions to be characterized agreed upon (with SIs 3–7). Decisions taken about which databases, seed bank management systems and web portals to build upon, and on the	*2012*

	kind of IT expertise required to implement the SI. Legal and publicity arrangements for creating a pre-competitive domain for data delivery designed and validated by legal and public relations experts.	
3.	Raw, simple version of the database behind the future web portal available and ready to accept molecular and trait data streams (milestone shared with MAIZE SI 8). CIMMYT- and ICARDA-held wheat collections meet best practice standards, as recognized by QMS or other certifications. New accessions collected from oasis and hot areas.	*2012*
4.	High-density genotyping-by-sequencing profiles for most accessions generated and uploaded to database. First version of the WHEAT Diversity Portal available to provide CRP members with on-line access to data streams (output shared with MAIZE SI 8). Compatible seed bank management systems deployed (milestone shared with MAIZE SI 8). Set of priority traits re-evaluated and adjusted. Marker-assisted pre-breeding pipeline established and work done on a number of priority cases for the global wheat-breeding community (with SI 4)	*2013*
5.	Evaluation completed of approximately 40 key agronomic, nutritional/grain quality, and biotic/abiotic stress related traits across trait-dependent sets of accessions. A second series of accessions selected for trait-specific phenotyping sets. Around 40 (preferably diagnostic) markers currently used for MAS in breeding programs assayed across most varieties. Approximately 40 genes with known functions sequenced across selected sets, with sequenced genes matching targeted traits.	*2014*
6.	Fully refined version of the WHEAT Diversity Portal completed and online (with SI 10). Critical diversity gaps in CIMMYT-, ICARDA- and partner-held ex situ wheat collections filled through collections in areas identified by gap analysis.	*2015*
7.	Field trials for second set of varieties/traits completed. Genomes of a set of thoroughly phenotyped accessions partially re-sequenced via exon-capture or skim-sequencing (if genome sequence available). Favorable translocations and alleles of (novel) genes conferring resistance/tolerance to abiotic/biotic stresses identified and uploaded to the WHEAT Diversity Portal, and made available through well-characterized parental stocks and accessions. Network of data miners adding value to the WHEAT Diversity Portal established. WHEAT Diversity Portal cross-linked with other on-line resources such as GeneSys, GrainGenes, GenBank, Gramene, HarvEST, and the Patent Lens.	*2016*

Outcomes

- The global wheat community will gain free access to a quantum leap in the understanding of the genomic variation and its potential uses for improvement of traits related to key agronomics, abiotic/biotic stress, and quality.
- Research and breeding programs worldwide will mobilize significantly more genetic variation from landraces, synthetics, wild relatives, and pre-bred parental stocks and will utilize the knowledge available through the WHEAT Diversity Portal.
- Key-trait donors and distilled information on phenotypic and molecular diversity will enable faster and more significant genetic gains in wheat-breeding programs worldwide.
- Breeders worldwide will use increasingly sophisticated – and more effective - breeding approaches for complex traits, supported by an understanding of the effects of distinct loci on physiological trait components.
- Breeding programs will achieve more effective "cisgenics" design, informed by new insights into gene functions, and derived from comprehensive marker-trait association studies.

Targets and estimated impacts

Global public and private wheat-breeding programs of any size and at any location, provided the "commons" philosophy is adhered to; wheat researchers at CIMMYT, ICARDA, universities, national research programs and advanced research institutes worldwide; wheat seed banks at national research programs and advanced research institutes; and policymakers and regulatory authorities promoting/regulating the conservation and use of wheat biodiversity.

This SI has very high leverage and impact potential. It will enable the wheat breeding and research community world-wide to: capture more genetic diversity in the ex situ collections and to more fully utilize the native genetic diversity contained in the genetic resources of wheat wild relatives; accelerate breeding gains; and counteract the combined and growingly negative effects of climate change and water, land, and nutrient scarcity. Genetic diversity is one essential component of breeding progress, and so far plant breeders have only utilized a small fraction of bio-resources.

Other issues

Risks and Opportunities: The objectives of this SI are ambitious, but recent advances in genomic and informatics sciences offer opportunities that compel WHEAT to invest in these high-potential-payoff pursuits.

Development interventions

Restrictive business practices and intellectual-property rights over basic biodiversity-related resources and knowledge increasingly pose barriers to the open exchange and use of the "raw materials" for crop breeding—the genes embedded in crop varieties stored in seed banks. CIMMYT and ICARDA are committed to the worldwide availability and sharing of the tools and products developed through this initiative, especially for the benefit of public sector researchers and breeders, and for small- to medium-scale agro-enterprises in the developing world. We will make the combined bio-assets of this SI openly available through mechanisms that discourage intellectual property protection of raw materials and basic knowledge, while promoting their enhanced use for the development of improved cultivars by both public and private players, for the ultimate benefit of farmers and consumers. For this purpose, we will pursue an open access “materials under development” strategy to keep the basic building blocks required for future breeding progress in the public domain.

Alignment with other WHEAT strategic initiatives

While the intent of SI 9 is to comprehensively characterize and evaluate the wheat ex situ holdings of CIMMYT and ICARDA, pragmatic approaches to subdivide the collections into more manageable operational subsets will be required. Sub-setting will target accessions and traits considered more likely to be of immediate use for breeders and researchers (SIs 5–7). Targeting will also rely on socioeconomic and livelihood factors obtained from SI 1. Particular attention will be paid to criteria related to wheat as a food in the targeted regions, including its processing (storage, milling, cooking), consumption (product diversity, acceptance and appeal) and nutritional safety and quality criteria, based in particular on the inputs, concerns and demands of women farmers, processors and heads of households (SI 1). Genetic variability necessary to adapt wheat to climate change will also be addressed.

To keep this SI pragmatically focused on user needs and to enable it to capture appropriate technologies (as opposed to be driven by technologies), the initiative will be externally reviewed and monitored by an advisory committee—comprising stakeholders drawn from various points in the value chain and technology advisors who monitor the rapidly evolving technology landscape. A separate user committee that will proactively involve women and young adult scientists will iteratively test the functionalities of the WHEAT Portal. Members will also serve in a training-of-trainers (SI 10) group to promote public awareness user guides at the end of the project and thus extend the impact of SI 9 data, information and applications into the future. These materials will feed into the appropriate breeding and genebank-management training modules used at CIMMYT and ICARDA. Pre-bred germplasm developed through the trait-introgression pipelines will be disseminated as global public goods through the NARS-mediated International Wheat Improvement Network, and to the centers’ research teams.

Lessons from the past

Rhetorical winds twist around the fields of plant genetic resources. Genebank collections are often heralded as “humanity’s most valued assets”, “repositories conserving humanity’s agricultural heritage”, and “essential if we will be able to adapt agriculture to a rapidly changing environment”. However, when pressed, applied breeders admit that they infrequently access germplasm from genebanks, and many consider that the collections consist merely of obsolete germplasm of little relevance to their current breeding needs (GCDT, 2006). Through this SI CIMMYT and ICARDA are committed to complement their obligations on more thorough wheat genetic resource conservation, and to improve the usability of conserved crop genetic diversity by adding and making accessible genetic and phenotyping characterization data.

Research methods

WHEAT SI 9 will be implemented in concert with MAIZE SI 8. The two strategy initiatives, therefore, will benefit from shared management and partly overlapping advisory and user committees and teams. Synergies resulting from the common use of DNA extraction and genotyping/sequencing technologies may be exploited by establishing a genotyping service unit to satisfy the demand generated by WHEAT SI 9 and MAIZE SI 8.

Molecular characterization: The arrival of next-generation sequencing technologies has initiated a transition from gel/hybridization-based molecular marker technologies to DNA sequencing as the method of choice for describing genetic polymorphisms. Marker technologies are converging toward the sequencing of genome representations (collections of genomic restriction fragments), a method commonly referred to as genotyping-by-sequencing (GBS). GBS will be our principal method of choice because it not only genotypes known SNPs but simultaneously also mines for new alleles and genotypes novel SNPs—an essential feature when characterizing seed banks. We will select a GBS method that enables us to implement a variable multiplexing level (genetic resolution). In this way not only can we describe the molecular makeup of the entire wheat collections at CIMMYT and ICARDA at a resolution of roughly 10^4 genomic fragments (about USD 7–10 per sample), we can also subsequently refine the genetic analysis for a subset of accessions at a much higher resolution for association mapping purposes. The resulting datasets will enable breeders to “reach out” into otherwise uncharacterized germplasm, using genome-wide fingerprints as a proxy for missing phenotypic descriptors in much the way geo-referenced passport data are sometimes used to select accessions.

Key traits: We will build on CIMMYT’s and ICARDA’s long-standing roles as the facilitators of networks to evaluate a selected set of key traits. Designated members of a phenotyping network will prioritize approximately 40 traits, agree on methodologies and protocols, target germplasm and evaluation environments and perform field trials. The SI will also co-fund a number of network members’ own trials, provided that they adhere to the Standard Operating Procedures and include a minimum set of reference accessions in their experiments.

Precision phenotyping: Extensive phenotyping of large field trials for several traits is highly expensive. However spectroradiometrical techniques may allow a fast and non-destructive screening of genotypes for several traits in multi-location field trials. Thus spectral reflectance of plant canopy is a non-invasive phenotyping technique that enables monitoring of several dynamic complex traits, such as biomass accumulation, with high temporal resolution. In addition other physiological characteristics of the plants, such as canopy architecture, plant water status, nitrogen concentration and even photosynthetic efficiency are captured in the spectra. Low cost alternatives such the use of spectroradiometers that only measure the few wavelengths required to calculate vegetation indices (such as the NDVI) may still allow the evaluation of biomass and to early predict final grain yield. Moreover these spectroradiometers (e.g. GreenSeeker) use active sensors (equipped with its own source of radiation) being therefore less influenced by environmental conditions but measure few wavelengths.

Diversity-delivery paths: We will build on and refine existing seed conservation and delivery operations at the CIMMYT and ICARDA seed banks according to best-practice management approaches, including automated intellectual property management. We will leverage our partnership with GBS providers to configure a precision-introgression pipeline, built around high-density genome-background selection and supported by custom-built software tools.

Sustainable long-term funding of the gene banks
Costs determined as "essential" for the conservation of wheat genetic resources have been removed from the WHEAT budget scenarios. SI 9 intends to add value to the collections held by CIMMYT and ICARDA by leveraging top-end genomic and phenotypic technologies, to uncover the genetic heritage of wheat and to build a platform that assists wheat researchers and breeders globally in targeted mobilization of novel diversity into breeding programs via well-characterized accessions and parental germplasm. These activities fall outside the purview of the Consortium and Global Crop Diversity Trust essential funding of the collections.

Research and development partners

- Wheat-phenotyping network participants at national research programs, advanced research institutes, universities, and the private sector.
- The Wheat Yield Consortium and GCP Challenge Initiatives.
- Sequencing and genotyping experts at Triticarte PL, Kbioscience, BGI-Shenzhen, CINVESTAV, and/or other organizations.
- Intellectual property experts at PIPRA and elsewhere.
- Information technology experts at universities, foundations, and in the industry.
- Genomics, genetics, and breeding software developers at universities.
- Data analyzers at universities (the Wheat Phenome Atlas project at University of Queensland), advanced research institutes, and companies.
- Wheat and intellectual property online resources at USDA-ARS/Cornell University (GrainGenes), NCBI (GenBank), University of California Riverside (HarvEST), Cornell University (Gramene), and CAMBIA (Patent Lens);
- National research programs and seed banks engaged in germplasm conservation and pre-breeding at USDA, NIAB, IPK, and AWCC.
- Global Crop Diversity Trust.
- Breeders at CIMMYT, ICARDA, national research programs, advanced research institutes, universities, seed companies, the Hybrid Wheat Consortium, and private-sector consortia mobilizing novel diversity into breeding programs via seed or introgression lines.
- Patent offices using the WHEAT Diversity Portal for evaluating prior art during the patenting process.
- Plant scientists worldwide using the WHEAT Diversity Portal, seeds or introgression lines for research.

SI 9 References

Crossa, J., Burgueno, J., Dreisigacker, S., Vargas, M., Herrera-Foessel, S.A., Lillemo, M., Singh, R.P., Trethowan, R., Warburton, M., Franco, J., Reynolds, M., Couch, J.H. and Ortiz, R. 2007. Association analysis of historical bread wheat germplasm using additive genetic covariance of relatives and population structure. *Genetics* 177: 1889–1913.

Crossa, J., Perez, P., de los Campos, G., Mahuku, G., Dreisigacker, S. and Magorokosho, C. 2010. Genomic prediction of quantitative traits in plant breeding using molecular markers and pedigree. (In press)

Dreisigacker, S., Kishii, M., Lage, J. and Warburton, M. 2008. Use of synthetic hexaploid wheat to increase diversity for CIMMYT bread wheat improvement. *Aust. J. Agric. Re.s* 59: 413–420.

Franco, J., Crossa, J., Taba, S. and Shands, H. 2005. A sampling strategy for conserving genetic diversity when forming core subsets. *Crop Science* 45: 1035–1044.

GCDT 2006. Global strategy for the ex situ conservation with enhanced access to wheat, rye and triticale genetic resources. Global Crop Diversity Trust, Rome. [http://www.croptrust.org/documents/cropstrategies/wheat.pdf]

Hawtin, Geoff, et al. 2011. The cost to the CGIAR centres of maintaining and distributing germplasm. CGIAR Consortium, Montpellier.

Keller, B., Yahiaoui, N., Mackay, M., Street, K. and Kaur, K. 2008. Allele mining and sequence diversity at the wheat powdery mildew resistance locus Pm3. The 11th International Wheat Genetics Symposium proceedings. Appels, Rudi, Eastwood, Russell, Lagudah, Evans, Langridge, Peter, Mackay, Michael, McIntyre, Lynne and Sharp, Peter (eds). Sydney, Sydney University Press.

Medini, M., Hamza, S., Rebai, A.and Baum, M. 2003. Analysis of genetic diversity in Tunisian durum wheat cultivars and related wild species by SSR and AFLP markers. *Genet. Resources Crop. Evol.* 52: 21–31.

Ogbonnaya, F.C., Bariana, H.S., Shankar, M., Hollaway, G.J., Imtiaz, M., Trethowan, R., Lagudah, E.S. and van Ginkel, M. 2008. Mining synthetic hexaploids for multiple disease resistance to improve wheat. *Aust. J. Agric. Res.* 59: 421–431.

Reynolds, M., Foulkes, M.J., Slafer, G.A., Berry, P., Parry, M.A.J., Snape, J.W. and Angus, W.J. 2009. Raising yield potential in wheat. *J. Exp. Bot.* 60: 1899–1918.

Roa-Rodríguez, C. and van Dooren, T. 2008. Shifting common spaces of plant genetic resources in the international regulation of property. *The Journal of World Intellectual Property* 11: 176–202.

Trethowan, R., Mujeeb-Kazi, A. 2008. Novel germplasm resources for improving environmental stress tolerance of hexaploid wheat. *Crop Science* 48: 1255–1265.

Warburton, M.L., Crossa, J., Franco, J., Mujeeb-Kazi, A., Trethowan, R., Rajaram, S., Pfeiffer, W., Zhang, P., Dreisigacker, S. and van Ginkel, M. 2006. Bringing wild relatives back into the family: recovering genetic diversity in CIMMYT improved wheat germplasm. *Euphytica* 149: 289–301.

Strategic Initiative 10. Strengthening capacities

Value proposition

Enhancing research capability of partner institutions and training a new generation of wheat professionals and farmers, as a basis for helping national wheat improvement programs, in partnership with CGIAR institutions and other important stakeholders, to improve the efficiency, impact, and sustainable intensification of wheat-based cropping systems.

Estimated impact	**2020**	**2030**
Increased numbers of scientists and technicians trained	100 scientists, technicians, and development partners trained per annum; 20 MSc and 10 PhD degrees conferred per annum.	
Benefit to the poor	*Direct*: Improved access to the knowledge of new technologies through strengthened development partners (NARSs, NGOs, CBOs, extension systems). *Indirect*: New higher yielding varieties, resistant/tolerant to biotic and abiotic stresses and with appropriate end-use quality, developed and disseminated faster through a well trained network of wheat researchers.	
Empowering resource-poor & women farmers	Through technical support (training, extension and technical materials) provided to NARSs, CBOs, NGOs and farmer organizations, at least 25,000 resource-poor wheat farmers (especially women) in at least 10 target developing countries shall be trained in improved wheat technologies/practices, leading to sustainable and enhanced wheat production.	
Benefit to the environment	Agronomists and breeders trained in the use of conservation agriculture principles and modern breeding tools to enable sustainable intensification of wheat production in developing countries.	
Others	Strengthening of national programs to increase the quality of data generated and managed by the global wheat breeding and agronomy networks, which in turn will lead 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 plant genetic resources, new tools and technologies, and to assure the food security of a world population that is projected to double by 2050. Internationally facilitated partnerships are required to strengthen the research, crop, and seed production capacity of key institutions in the developing world in a fair and responsive manner to achieve sustained impact.

A major constraint to wheat research and development in public and small private institutions in many developing countries is the insufficient number of skilled, well-prepared scientists and technicians (research support staff). What most wheat programs of the national agricultural research systems ask from CIMMYT are long-term, hands-on, interdisciplinary wheat improvement courses (including aspects of breeding, pathology, agronomy, physiology, grain quality, molecular breeding and applied statistics) for young researchers. These programs also seek opportunities for mid-career professionals to focus on leveraging the power of modern crop science to develop sustainable, productive, profitable and socially acceptable cropping systems for resource-poor farmers in the developing world. In order to attract a greater number of students to plant breeding and related disciplines, university instructors need training support, especially on the latest advances in plant breeding and agronomy.

Although many existing and emerging seed companies in developing countries are registering and producing varieties derived from CIMMYT and ICARDA lines, current production does not meet demand. Lack of well functioning breeder seed production within public NARSs remains a major constraint contributing to long-time lags between release and availability of seed for large-scale multiplication. Local seed companies' knowledge—particularly in seed enterprise formation and in management and skills in quality seed production—need strengthening. Similarly, training and partnerships with small- and medium-sized agricultural machinery manufacturers can stimulate local development and marketing of suitable and affordable conservation agriculture implements.

Resource-poor farmers, especially women, require training to unleash the full potential of new varieties and knowledge-intensive crop management practices. Strengthening the capacity of development partners (international centers, national research systems, seed companies, NGOs, community-based organizations, and farmers' organizations) to provide this training and to facilitate researcher-farmer and farmer-to-farmer information flow is a crucial prerequisite to strengthening crop and seed production capacity in much of the developing world.

Results of research-for-development activities in the form of knowledge, data sets, extension and learning materials are considered global public goods, and as such shall be made available in an openly accessible way (primarily through internet-based applications).

Although capacity building forms a separate SI within WHEAT, all key activities will be planned and implemented in coordination with the other SIs. Courses will primarily be delivered by specialists from CIMMYT and ICARDA, and we will also draw on our extensive network of collaborators (from NARSs, ARIs, universities and the private sector), including alumni. Similarly, training materials will be prepared in close collaboration with specialists. The embodiment of SI 10 as a specific initiative will enable a high level of continuity in delivery, coordination across disciplines, and ongoing focus on quality standards and sharing of best practices, both in training and knowledge management.

Why international agricultural research?
An internationally facilitated partnership is needed to strengthen the research capability, infrastructure and seed-production capacity of key institutions in the developing world, and to achieve and sustain impact. CIMMYT's and ICARDA's strong strategic partnerships with national agricultural research systems, other international centers, the private sector, universities, agricultural research institutions and non-governmental organizations enable them to carry out capacity building at various levels. CIMMYT and ICARDA are world leaders in wheat improvement and agronomy, and also have extensive experience and skills in wheat seed production and seed systems, especially in the developing world. Both centers have a 40-year history and excellent reputations for capacity building in practically all wheat-growing countries in the developing world. More than 5,000 developing country researchers have participated in training courses or served as visiting scientists at these two centers. Unlike most academic institutions in developing countries, CIMMYT and ICARDA conduct large-scale multidisciplinary research activities that enable both informal and formal hands-on training of partners from developing countries in Africa, Asia, and Latin America.

Professional development of MSc and PhD candidates is enhanced when they conduct their thesis research at CIMMYT or ICARDA. Many former trainees now teach in universities or hold leadership positions in the national agricultural research systems—an indicator of the quality of these training programs. This SI will create a new generation of professionals to: enhance the efficiency and impact of wheat research and development; support strengthening of the infrastructure (where relevant) and the overall breeding capacity of partner institutions; foster the empowerment of resource-poor farmers in the target developing countries, with a focus on women.

Outputs

1. At least two training modules developed every year and made accessible (for example, through e-learning modules) to the wheat scientific community, including NARSs and universities, in areas of need identified by SIs 2–9. Examples may include:
    - Management of high-throughput, low-cost screening methods for key target traits that increase selection gains for abiotic and biotic stress tolerance, water- and nutrient-use efficiency, and nutritional quality traits (SIs 3–6).
    - Conventional and molecular wheat breeding and pathology (including use of marker-assisted selection and trial management) (SIs 4–7).
    - The effective and beneficial conservation and use of genetic resources (SI 9).
    - Data management and analysis; biometric analyses and simulation of breeding methodologies (SIs 2–7).
    - Techniques of good quality seed production; seed business management; seed certification (SI 8).
    - Principles and practice of conservation agriculture in wheat-based farming systems; integrated disease and insect-pest management; and integrated nutrient management (SIs 2–3).

- Post-harvest problems, mycotoxin contamination, and post-harvest technological interventions (SIs 2, 3 and 5).
- Wheat seed systems and input value chains, policy and wheat-market analysis; technology targeting, up-scaling and impact analysis (SIs 1–3).
- Efficient management of applied research programs; technical writing (proposals, reports, research papers).

2. Interdisciplinary and specialized international, regional and in-country training courses conducted by subject matter specialists, targeted for young and mid-career wheat scientists (and related disciplines) and imparted every year to more than 100 researchers and support staff (technicians) from both public and private sectors in developing countries. Advocating for and supporting professional development of science managers to enhance continuity of quality wheat research in developing countries.
3. At least 20 personnel from NARSs, the private sector, NGOs and CBOs trained in seed production and seed systems annually to enhance their capacity to promote and conduct quality seed production.
4. At least 10 MSc students in developing countries supported each year to conduct research toward their degrees—in collaboration with and under guidance of CIMMYT and ICARDA scientists.
5. Diverse extension materials (fact sheets, posters, bulletins, radio and video scripts and files, etc.), methodologies, and decision-making support tools developed, utilized and made accessible in centralized online repository. These resources will ensure effective and high-impact dissemination of information and knowledge on important aspects, covering vital topics such as in-situ conservation of genetic resources, post-harvest management and conservation agriculture.
6. Technical support given to NARSs, CBOs, NGOs and local seed companies in targeted developing countries to train at least 25,000 farmers, especially resource-poor women, in the above-listed disciplines by 2020.
7. Tools for efficient data-management and analysis in crop management and breeding research 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.
8. Knowledge, information, and data-resulting research and development activities managed and shared in several web-based applications, including International Wheat Improvement System (IWIS), Wheat Atlas, Wheat Doctor, Wheat Diversity Portal, and repository of extension materials.

SI 10 Outputs and Corresponding Key Milestones

	2011	2012	2013	2014	2015	2020
Output 1: Two training modules developed and made publicly available every year.	**1***	**1**	**1**	**1**	**1**	**1**
Output 2: Training courses supporting professional development of wheat scientists and technical staff.	**1, 2**	**1, 2**	**1, 2**	**1, 2**	**1, 2**	**1, 2**
Output 3: At least 20 personnel trained in seed production and seed systems annually.	**1, 2**	**1, 2**	**1, 2**	**1, 2**	**1, 2**	**1, 2**
Output 4: Graduate students supported each year to conduct research toward their degrees.	**3**	**3**	**3**	**3**	**3**	**3**
Output 5: Extension materials made accessible in a centralized online repository.	**1, 4**	**1, 4**	**1, 4**	**1, 4**	**1, 4**	**1, 4**
Output 6: Technical support given to NARSs, CBOs, NGOs and local seed companies to train farmers.	**1, 2, 5, 6**	**1, 2, 5, 6**	**1, 2, 5, 6**	**1, 2, 5, 6**	**1, 2, 5, 6**	**1, 2, 5, 6**
Output 7: Tools for data-management and analysis in crop management and breeding research.	**1**	**1**	**1**	**1**	**1**	**1**
Output 8: Web-based applications including the International Wheat Improvement System (IWIS), Wheat Atlas, Wheat Doctor, and Wheat Diversity Portal.	**1**	**1**	**1**	**1**	**1**	**1**

*Refer to numbered milestone descriptions in the text

SI 10 Key Milestones

1.	At least two publicly available learning modules/materials developed annually in key areas of wheat research and development, using diverse formats (including multimedia).	*Annually*
2.	At least two in-country/regional courses and two international courses conducted annually for training of at least 150 researchers and seed specialists from national agricultural research and extension systems, the private sector and other stakeholders.	*Annually*
3.	At least 10 students will conduct their thesis research in collaboration with CIMMYT and ICARDA every year.	*Annually*
4.	At least three multi-format extension materials developed every year.	*Annually*
5.	Development partners from NGOs, CBOs etc. updated annually/biannually on new technologies available for mass scale dissemination.	*Annually*
6.	4,000 farmers trained in conservation agriculture annually through partnerships with SI2, community-based organizations, local seed companies and national agricultural research and extension systems.	*Annually*

Outcomes

- Increased capacity of partner institutions to introduce, adapt and use new tools and methods, and increased efficiency in developing new wheat varieties with abiotic and biotic stress tolerance/resistance and improved nutritional and industrial quality.
- Increased capacity of partner institutions to conduct adaptive agronomic research for the development of sustainable farming systems.
- Strengthened professional capacity of national agricultural research and extension systems, emerging seed companies, nongovernmental organizations and community-based organizations to produce and promote quality wheat seed.
- Strengthened professional research capacity of national agricultural research and extension system partners to design and manage sustainable, efficient long-term wheat-breeding programs and agronomic research.
- Enhanced plant-breeding and sustainable-systems curricula at universities and other educational institutions in target developing countries.
- Strengthened regional and global networks of wheat scientists, and international collaboration among research and academic institutions.
- Streamlined open access to data, information and knowledge produced by CIMMYT, ICARDA and the International Wheat Improvement Network (IWIN)

Targets and estimated impacts

National agricultural research and extension systems in developing countries of Asia, Africa, and Latin America that engage in wheat research and development (especially those NARSs lacking sufficient human and financial resources); public/private institutions and universities that engage in wheat research and development in those same developing countries; and resource-poor farmers (especially women) in target developing countries in the above-listed regions.

Quantified impact pathways

A minimum of 1,000 scientists, teachers and technicians, and 150 postgraduate students from public and private sector institutions of developing countries, to be involved in wheat R&D and trained in key areas of modern breeding, agronomy and socioeconomic analysis—leading to enhanced efficiency and impact. Research facilities and tools for wheat improvement and agronomy strengthened in at least 10 strategic locations in sub-Saharan Africa, Asia, and Latin American countries, leading to significant reductions in time and cost to identify donors for important traits and their consequent utilization in breeding programs. Training and empowerment through NARSs, CBOs and NGOs of at least 25,000 resource-poor wheat farmers, especially women, in at least 10 target developing countries by 2020, to give them skills in improved wheat technologies and practices that will lead to sustainable and enhanced wheat production.

Gender

Both women and men manage sectors of complex research that affects smallholder production systems. When gender is ignored, there is a cost to society's wellbeing and sustainable growth. Knowledge is not transferred; it is generated and exchanged in continuous learning processes (World Bank 2009). We applaud the Borlaug Global Rust Initiative's recent scholarship program—the Jeanie Borlaug Laube Women in Triticum Award—that provides professional development opportunities for women working in wheat during the early stages of their careers. WHEAT is committed to affirmative actions that will increase the number of trained women and young adult wheat researchers, and we will commit to reserving at least 30% of all WHEAT-sponsored training positions for qualified women wheat researchers.

Research and development partners

- The FAO, through the Global Partnership Initiative for Plant Breeding Capacity Building (GIPB): priority setting, both geographic and thematic (FAO 2005).
- International agricultural research centers (CIMMYT, ICARDA, Bioversity, IRRI): priority setting, resource personnel, content, venues, development of learning materials, coordination.
- Advanced research institutions: resource persons, development of learning materials.
- Leading institutions/universities in national agricultural research and extension systems (Brazil, China, India, Mexico): priority setting, venues, resource personnel, learning and extension materials development.
- Public and private seed companies: resource personnel, learning materials development.
- National agricultural research and extension systems: priority setting, needs assessment.
- Public and private molecular laboratories: venues, resource personnel.
- Non-governmental organizations, community-based organizations, and seed trade associations: extension, extension materials development and dissemination.

Development partners capable of utilizing and up-scaling capacity-building outputs include: NARSs, IARCs (CIMMYT, ICARDA), FAO, ARIs, private industry, trade associations, national and international NGOs, existing and/or emerging public and private seed companies, community-based organizations, and variety release and seed certification agencies.

What's new in this initiative?

- Collaboration with national universities on updating their course materials and curricula.
- Comprehensive (holistic) mega-program approach to capacity building in the area of wheat improvement, agronomy and related disciplines.
- Strengthening the capacity of partner institutions for enabling high-throughput screening of germplasm and breeding materials.

SI 10 References

FAO 2005. Plant breeding and related biotechnology capacity assessments. (http://gipb.fao.org/Web-FAO-PBBC/index.cfm?where=01).

World Bank 2009. World Bank, Food and Agriculture Organization, and International Fund for Agricultural Development, Gender in Agriculture Sourcebook. Washington, DC: World Bank.

Annex A. Research areas prioritized by at least two partner organizations as being important for WHEAT. The final decision on research areas included in WHEAT was based on the importance for the poor in developing countries, the comparative advantage of international agricultural research and the role of alternative suppliers.

	Research areas included in WHEAT	Research areas outside of WHEAT	Examples of location of research
	Socioeconomic research		
SI1	Socioeconomic research targeted at wheat food security and systems relevant to the poor	Wheat data bases	FAO
	Agronomy research		
SI2	Particpatory research on crop adaptation to conservation agriculture in main/regionally important wheat-based systems	Research on crop adaptation to conservation agriculture in local systems	NARS
	Reduced or low input systems: NUE, WUE	CA machinery design and manufacture	Private Sector
	Double cropping suitability; bed and late sowing	Extension of CA systems	NARES
	Supplementary or irregular irrigation applications, deep sowing	Herbicide tolerance	US, Europe
	Dual use: grain and forage	High input systems	Europe, China
		Wheat for biofuel	UK
SI3	Nutrient use efficiency (N, P) and biological nitrification inhibition in an applied context	Basic research on nutrient use efficiency and biological nitrification inhibition	Universities
	Precision agriculture adapted to resource-poor farmer conditions	Nutrient use efficiency on nutrients other than N and P	eg Australia and Turkey (Zn)
		Growth enhancer response	Private sector
		Precision agriculture for large-scale farmers	Australia, Europe, US, South America
	Breeding, use and quality research		
SI4	Trait integration for yield stability in the developing world with focus on poorest regions	High latitude wheat; trait integration for yield stability in the developed world	Australia, Canada, China, Europe, Russia, US
	Quality for: Flat breads, leavened bread, noodles, pasta, bulgur	Dual purpose, grazing/grain breeding	Europe, US, China
	Glutenin diversity	Wheat for biofuel	UK
	Grain yield potential and stability	Quality for: cookies, cakes, steamed bread, waxy grain	Australia, China, Europe, US
	Iron & Zinc concentration in grain	Essential amino-acid composition	US
		Feed grain quality	Europe
		Grain antioxidants	US, Australia
		Grain vitamin A concentration	CRP4
		Late-maturity alpha amylase reduction	Australia, Europe, US
		Pre-harvest sprouting tolerance	Australia, Europe, US

Table continues on following pages.

Annex A continued). Research areas prioritized by at least two partner organizations as being important for WHEAT. The final decision on research areas included in WHEAT was based on the importance for the poor in developing countries, the comparative advantage of international agricultural research and the role of alternative suppliers.

	Research areas included in WHEAT	Research areas outside of WHEAT	Examples of location of research
	Biotic stresses		
SI5	Biotic stresses > 5 million ha and with significant impact on food security in the developing world	Biotic stresses with local importance or mostly important in the developed world	
	Cereal cyst nematode resistance	Bacterial diseases	Canada
	Fusarium crown rot resistance	Bird-cherry oat aphid	UK
	Fusarium scab resistance	BYDV resistance	Europe
	Helminthosporium leaf blight resistance	Cereal leaf beetle	Europe
	Karnal Bunt	Common bunt and smut	Iran, Turkey
	Leaf rust (major & minor genes)	Fungicide efficacy	Private Sector
	Root lesion nematode resistance	Fusarium toxin suppression	USA, France, Austria
	Septoria tritici resistance	Green bug	US, Egypt
	Stem Rust (major & minor genes)	Helminthosporium common crown rot resistance	Australia
	Sunn Pest resistance	Powdery mildew resistance	China, Europe
	Tan-spot resistance	Rhizoctonia resistance	Australia
	Wheat blast resistance	Russian Wheat Aphid resistance	US, South Africa
	Yellow rust (major & minor genes)	Saw Fly resistance	US, Morocco
	Hessian Fly resistance	Septoria nodorum resistance	Europe
		Sharp eye-spot	France
		Take-all resistance	UK
		Virus diseases	Europe, US
		Weed Alleopathic traits	Canada
		Weed competitiveness	Canada
		Wheat bulb fly	UK
	Abiotic stresses		
SI6	Earliness (flowering and maturity)	Acid soils / Aluminum	Brazil
	Heat tolerance	Boron-deficiency	Bangladesh
	Salinity tolerance	Boron-toxicity	Australia
	Water use efficiency and drought tolerance	Extensive root architecture	UK
		Floral frost tolerance	Australia
		Pubescent leaves	UK
		Sodicity tolerance	Australia
		Thick leaves	UK
		Waterlogging tolerance	Australia
		Waxy leaves	UK USA
		Zinc-deficiency in the soil	Turkey
	Yield potential research		
SI7	Wheat genetic variation for photo-synthesis efficiency and biomass productivity including early canopy vigor	Basic research on photosynthesis efficiency	Universities
	Lodging tolerance associated with more productive wheats	Selection for lodging tolerant wheat in routine breeding programs	NARS
	Heterotic grouping and genetic stocks to be used for germplasm trageted at the dveeloping world	Hybridization approaches: anther extrusion, apomixis, cytoplasmic male sterility and sterility (floret) alleviation; blue aleurone for assessing hybrid seed segregation; GM based approaches	Europe, US, Australia, India, China; private setcor

Table continues on the following page.

Annex A (continued). Research areas prioritized by at least two partner organizations as being important for WHEAT. The final decision on research areas included in WHEAT was based on the importance for the poor in developing countries, the comparative advantage of international agricultural research and the role of alternative suppliers.

	Research areas included in WHEAT	Research areas outside of WHEAT	Examples of location of research
	Seed systems		
SI8	Research into seed systems	Certified and Commercial seed production	Private Sector
	Breeder seed production for new technologies (introduction phase only)	Implementation of improved seed systems	FAO
	Diversity analysis and use		
SI9	Landrace improvement	1B/1R diversity	US, Europe
	Rye translocations	Alternative dwarfing genes (coleoptile)	Australia
		Crossability with rye	USA Sweden
		Cytogenetic stocks	UK, USA, Russia
		Diversity analysis of winter wheat	Europe, US
		Spelt and emmer use and improvement	India, Europe
	Training		
SI10	Applied training and knowledge management as it applies to implementing the WHEAT research agenda	Generic and local training; training of extension agents and farmers	Universities, NARS

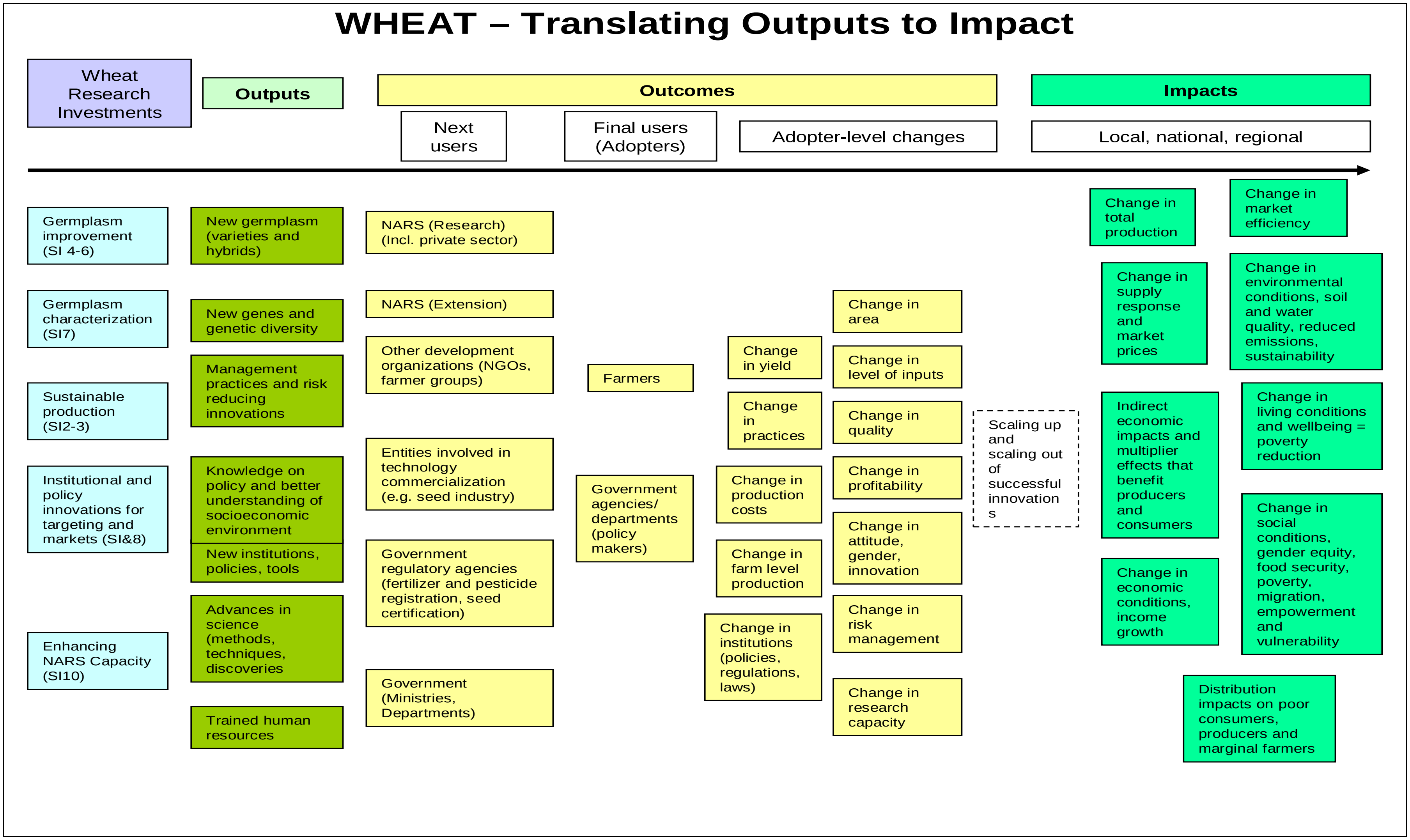
Annex B. Impact pathways for WHEAT: Factors involved in translating outputs into outcomes and impact[20]

Main outputs of WHEAT 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 (HY). • Nutritious and healthy grain.	• NARS partners adapt the new HY varieties to local conditions. • NARS 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. • Increased yield stability. • Greater price stability. • Area expansion. • Increase in wheat production by farmers. • Reduction in the cost of wheat production. • Increase in marketable surplus • Increased profitability.	• Increased participation of seed companies for production and wider diffusion of HY 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 to increase real incomes of the poor and make food more affordable to net-buyers. • Increase in production, contributing to local employment and income. • Increased farm household income. • Reduced poverty.
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 and more stable 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 wheat price fluctuation (resulting from stability of production). • Increased adaptation to climate change.

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

Main outputs of WHEAT 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**
3. Crop and resource management practices and knowledge • Minimum or zero till. • Crop rotations. • Crop residue retention. • Soil and water management. • Weed control. • Integrated pest management.	• NARS partners integrating better management into wheat cropping systems. • Extension systems unpack relevant information and demonstrate best bets 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 and more stable yields. • Increased farm level production. • Lower input use per hectare (labor, fossil fuels, fertilizer, pesticides, irrigation water, etc.). • Reduced production costs. • Higher profitability of wheat 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 (fertilizer, 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 WHEAT 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 wheat 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 agents 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 wheat-based farming systems.
5. Capacity enhancement • Trained human resources. • Physical infrastructure for research.	• NARS use new skills and infrastructure to generate and deploy wheat 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 wheat 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 wheat systems. • Local ability for policy analysis of future options. • Better policies to tackle climate change and ensure food security in wheat.



Annex B. Figure 1. Research interventions, outputs, outcomes and impacts for WHEAT.

Annex C. Partners who have sent letters supporting WHEAT.

	Name, position, institution	Country
1	**T.S. Jayne** Professor, International Development Michigan State University (MSU), USA	USA
2	**Christopher B. Barrett, Stephen B. and Janice G. Ashley** Professor of Applied Economics and Management Cornell University	USA
3	**Ragnar Øygard** Head of Department Norwegian University of Life Sciences, Norway	Norway
4	**A.H.M.Humayun Kabir** Deputy Managing Director Supreme Seed Company Ltd, Bangladesh	Bangladesh
5	**P. Stephen Baenziger** Eugene W. Price Professor University of Nebraska	USA
6	**Mario Allegri** Latin American Center for Rural Development (LACRD), Chile	Chile
7	**Francisco Javier Mayorga Castaneda** Secretary of Agriculture Mexico (SAGARPA)	Mexico
8	**Victor M. Villalobos** Director General Inter-American Institute for Cooperation on Agriculture (IICA),	Costa Rica
9	**Sumita Dasgupta** Under Secretary Indian Council of Agricultural Research (ICAR)	India
10	**IARI-CIMMYT Consultation meeting** Indian Agricultural Research Institute (IARI), India	India
11	**David Porter** Professor **Bill Raun** Regents Professor Oklahoma State University	USA
12	**Ignacio Solis Martel** Director Agrovegetal SA	Spain
13	**BARI-CIMMYT Consultation meeting** Bangladesh Agricultural Research Institute (BARI), Bangladesh	Bangladesh
14	**Wais Kabir** Chairman Bangladesh Agricultural Research Council (BARC), Bangladesh	Bangladesh
15	**Faisal Awawdeh** Director General National Center for Agricultural Research And Extension (NCARE), Jordan	Jordan
16	**Perry Gustafson** Missouri State University	USA
17	**Zoltan Bedo** Director Agricultural Research Institute, Hungary	Hungary

	Name, position, institution	Country
18	**Richard Trethowan** Professor University of Sydney, Australia	Australia
19	**Halim BEN HAJ SALAH** General Director Institut National des Grandes Cultures (INGC), Tunisia	Tunisia
20	**Marian VERZEA** General Director Academy of Agricultural and Forestry Sciences, Romania	Romania
21	**Jesús Santillano Cázares** Professor Universidad Autónoma de Baja California, México	Mexico
22	**Peter Freymark** Research Coordinator and **Lloyd Le Page** Sustainable Development Partnerships Pioneer Hi-Bred International, USA	USA
23	**Nick Austin** Chief Executive Officer Australian Centre for International Agricultural Research (ACIAR), Australia	Australia
24	**Brian Keating** Director, Sustainable Agriculture Flagship and **Jeremy Burdon** Chief, Plant Industry Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia	Australia
25	**Conxita Royo** Coordinator, Field Crops R+D and Head, Cereal Breeding Programmes Institute for Food and Agricultural Research and Technology (IRTA), Spain	Spain
26	**Jean-Marcel Ribaut** Director Generation Challenge Program (GCP), Mexico	Mexico
27	**S Kenebayev** President Kaz AgroInnovations JC, Kazakhstan	Kazakhstan
28	**Abdolali Ghaffari** Director General Dryland Agricultural Research Institute, Iran	Iran
29	**Dr. Muhammad Yasin** Director Indonesian Cereals Research Institute (ICERI), Indonesia	Indonesia
30	**Denis T. Kyetere** Director General National Agricultural Research Organization (NARO), Uganda	Uganda
31	**Ephraim A. Mukisira** Director Kenya Agricultural Research Institute (KARI), Kenya	Kenya
32	**Monty Jones** Executive Director Forum for Agricultural Research in Africa (FARA), Ghana	Ghana

	Name, position, institution	Country
33	**Seyfu Ketema** Executive Director Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA),	Uganda
34	**Mario Allegri** President Forum for the Americas on Agricultural Research and Technology Development (FORAGRO),	Uruguay
35	**Mohammad S. Muya** Permanent Secretary Ministry of Food, Agriculture, Food Security and Cooperatives,	Tanzania
36	**Roberto Díaz** Principal Investigator, National Agricultural Research Institute of Uruguay (INIA)	Uruguay
37	**Seyed Ata Rezaei** Director General Bureau of International Scientific Relations and **Jahangir Porhemmat** Deputy Minister and Head Agricultural Research, Education and Extension Organization, (AREEO)	Iran
38	**Solomon Assefa** Director General Ethiopian Institute of Agricultural Research (EIAR), Ethiopia	Ethiopia
39	**Wheat-Stakeholder meeting** Ethiopian Institute of Agricultural Research (EIAR), Ethiopia	Ethiopia
40	**Zeynal Akparov** Director Genetic Resources Institute National Academy of Sciences, Azerbaijan	Azerbaijan
41	**Roz Naylor**, Professor and Director **Wally Falcon**, Professor (Emeritus) and Deputy Director **David Lobell**, Assistant Professor and Fellow Stanford University, USA	USA
42	**Hugh Wallwork** (personal feedback) Principal Research Officer South Australian Research and Development Institute, Australia	Australia
43	**Carmen Thönnissen** Senior Advisor Swiss Agency for Development and Cooperation (SDC), Switzerland	Switzerland
44	**Hukmatullo Ahamdov** President Tajir Academy of Agricultural Sciences, Tajikistan	Tajikistan
45	**Liu Jianjun,** Research professor/senior breeder, Shandong Academy of Agricultural Science **Wang Fahong,** Research professor/senior agronomist, Shandong Academy of Agricultural Science **Lei Zhengsheng,** Research professor/senior breeder, Henan Academy of Agricultural Science **Yang Wuyuan,** Research professor/senior breeder, Sichuan Academy of Agricultural Science	China
46	**Huajun Tang** Vice-President for International Collaboration, Chinese Academy of Agricultural Science	China

Annex D. List of Current Partners (abridged[21]) (68 funded[22]—219 total)

National Agricultural Research Institutes (33 funded/86 total)

Albania, ATTC-Lushnje
Argentina, INTA
Azerbaijan, Institute of Genetic Resources
Bangladesh, Bangladesh Agricultural Research Institute (BARI)
Bangladesh, Agricultural Research Council (BARC)
Belarus, Institute of Arable Farming and Plant Breeding
Belarus, Institute of Genetics and Cytology of NASB
Brazil, EMBRAPA
Bulgaria, Institute of Plant Genetic Resources "K. Malkov"
China, Chinese Academy of Agricultural Sciences
China, Dryland Farming Institute
China, Gansu Academy of Agricultural Science
China, Heilongjiang Academy of Agricultural Science
China, Henan Academy of Agricultural Science
China, Ningxia Academy of Agricultural Science
China, Shandong Academy of Agricultural Science
China, Sichuan Academy of Agricultural Sciences
China, Xinjiang Academy of Agricultural Science
China, Yunnan Academy of Agricultural Sciences
China, Zhoukou Academy of Agricultural Science
Ecuador, INIAP
Egypt, Agricultural Research Council (ARC)
Ethiopia, Ethiopia Institute of Agricultural Research (EIAR)
Georgia, Georgian Institute of Farming, Field Crops PGR
India, Agharkar Research Institute
India, CSSRI
India, Directorate of Wheat Research (DWR)
India, Indian Council of Agricultural Research (ICAR)
India, Indian Agricultural Research Institute (IARI)
Indonesia, Indonesian Cereals Research Institute (ICERI)
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)

[21] This list may unintentionally exclude donor stakeholders, and participants involved in the International Wheat Improvement Networks (IWIN).
[22] Receiving funds from WHEAT projects (2010).

Iran, Iranian Research Institute for Plant Protection (IRIPP)
Iran, Seed and Plant Improvement Institute (SPII)
Iran, Soil and Water Research Institute (SWRI)
Iraq, Ministry of Sciences and Technology
Iraq, Mosul State Board for Agricultural Research
Jordan, National Center for Agricultural Research and Extension
Kazakhstan, Aktobe Agricultural Research Station
Kazakhstan, Karabalyk Agricultural Research Station
Kazakhstan, Kazakh Institute of Plant Protection
Kazakhstan, Kraganda Agricultural Research Institute
Kazakhstan, Pavlodar Agricultural Research Institute
Kenya, Kenya Agricultural Research Institute (KARI)
Lebanon, Rayak Agricultural Research Institute
Mexico, Cinvestav
Mexico, FIRA
Mexico, INIFAP-CEVAMEX
Mexico, Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP)
Mexico, Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion
Mexico, UAM
Mongolia, PSARTI
Morocco, INRAM
Nepal, Agriculture Botany Division, NARI
Nepal, Department of Agriculture
Nepal, Nepal Agricultural Research Council (NARC)
Pakistan, Ayub Research Institute
Pakistan, Pakistan Agricultural Research Council (PARC)
Philippines, PCAARD
Republic of Korea, Rural Development Administration
Romania, National Agricultural Research and Development Institute, Fundulea
Russia, Altay Agricultural Research Institute
Russia, Chelyabinsk Agricultural Research Institute
Russia, Kurgan Agricultural Research Institute
Russia, Omsk Agricultural State University
Russia, Siberian Agricultural Research Institute
Sudan, Agricultural Research Corporation (ARC)
Syria, Ministry of Agriculture
Tajikistan, RNCGR
Tanzania, Ministry of Agriculture
Turkey, Aegean Agricultural Research Institute
Turkey, Anatolian Agricultural Research Institute
Turkey, Bahri Dagdas International Agricultural Research Institute

Turkey, Central Field Crop Research Institute
Turkey, CRIFC Turkey
Turkey, General Directorate of Agricultural Research
Turkey, Sakarya Agricultural Research Institute
Turkey, Trakya Agricultural Research Institute
Turkmenistan, Turkmen Research Institute of Grain
Tunisia, Institut National des Grandes Cultures (INGC)
Uganda, National Agricultural Research Organization (NARO)
Ukraine, NCPGRU, Ukraine
Uruguay, INIA-La Estanzuela
USA, USDA-ARS

Regional and International Organizations (0 funded/13 total)
Australia, Australia Centre for International Agricultural Research
Ethiopia, International Livestock Research Institute (ILRI)
India, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Italy, Bioversity International
Italy, CAS-IP
Italy, Food and Agriculture Organization (FAO) of the United Nations
Italy, Global Crop Diversity Trust
Ghana, Forum for Agricultural Research in Africa (FARA)
Philippines, International Rice Research Institute (IRRI)
Sri Lanka, International Water Management Institute (IWMI)
Uganda, Association for Strengthening Agricultural Research in East and Central Africa (ASARECA)
Uruguay, FORAGRO
USA, International Food Policy Research Institute (IFPRI)

Universities (14 funded/56 total)
Armenia, Yerevan, Armenian State Ugrarian University
Australia, Adelaide, Flinders University
Australia, Adelaide, University of Adelaide
Australia, Brisbane, University of Queensland
Australia, Sydney, University of Sydney
Austria, Tulln, Vienna University of Technology
Belgium, Leuven, K.U. Leuven
Belgium, Louvain-La-Neuve, UCL
China, Beijing, China Agricultural University
China, Nanjing, Jiangsu, Nanjing Agricultural University
China, Yangling, Shaanxi, Northwestern Agroforestry Science and Technology University
China, Huazhong Agricultural University
Germany, Bonn, University of Bonn

Germany, Goettingen, University of Goettingen
India, Bhatinda, Punjab Agriculture University (PAU)
India, Coochbehar, UBKV (Uttarbanga Krish Vishvidyalaya)
India, Dharwad, University of Agricultural Sciences
India, Faizabad, NDUAT
India, Hisar, HAU
India, Kushinagar, KVK, IIVR
India, Pantnagar, GBPUAT
India, Ranchi, BAU
India, Samastipur, RAU, Pusa
India, Varanasi, Banaras Hindu University
Iraq, University of Baghdad
Iraq, Mosul University
Iraq, University of Sulimani
Israel, ICCI/Tel Aviv University
Italy, Bologna, University of Bologna - DISTA
Italy, Piacenza, Università Cattolica del Sacro Cuore
Japan, Tottori, Laboratory of Plant Breeding and Genetics, Tottori University
Malaysia, Penang, Universiti Sains Malaysia
Mexico, Baja California, Universidad Autonoma de Baja California
Mexico, Sonora, ITSON
Mexico, Texcoco, Colegio de posgraduados
Mexico, Texcoco, Universidad Autonomo de Chapingo
Norway, Aas, University of Life Sciences
South Africa,Bloemfontein, University of the Free State
South Africa, Stellenbosch, Stellenbosch University
Spain, Cordoba, Andalucia, Universidad de Cordoba
Spain, Lerida, Catalunya, IRTA
Sweden, Uppsala, Sverige Landbruksuniversietit, SLU
Turkey, Istanbul, Sabanci University
UK, Sheffield, University of Sheffield
UK, Silsoe, Cranfield University
USA, College Station, TX, Texas A&M University
USA, Corvallis, OR, Oregon State University
USA, Davis, CA, University of California-Davis
USA, Fort Collins, CO, Colorado State University
USA, Ithaca, NY, Cornell University
USA, Lincoln, NE, University of Nebraska
USA, Manhattan, KS, Kansas State University
USA, Pullman, WA, Washington State University

USA, St. Paul, MN, University of Minnesota
USA, Stanford, CA, Stanford University
USA, Stillwater, OK, Oklahoma State University

Advanced Research Institutes (0 funded/15 total)
Australia, Commonwealth Scientific & Industrial Research Organization (CSIRO)
Canada, Agriculture and Agri-Food Canada
Canada, Field Crop Development Center
Denmark, University of Aarhus, Dept. of Integrated Pest Management
France, INRA-Grignon
Hungary, Martonvasar, Hungarian Academy of Agricultural Sciences
Hungary, Research Centre for Agrobotany
Italy, National Research Council - Institute of Sciences of Food Production (ISPA)
Japan, JIRCAS
Japan, NARO
Mexico, Generation Challenge Program
Netherlands, Plant Research International
UK, Natural Resources Institute (NRI)
UK, Biotechnology and Biological Sciences Research Council (BBSRC)
UK, Scottish Agricultural Research Institute (SCRI)

Private Sector Organizations (1 funded/15 total)
Australia, Diversity Arrays Technology Pty. Ltd. (DArT)
China, Limagrain China
France, Club 5 = Eurodur + Syngenta + Deprez + Serasem + Limagrain
India, Mahyco
Italy, Produttori Sementi Bologna
Kazakhstan, "Fiton" Breeding Company
Mexico, Grupo Produce Estado de Mexico A.C.
Mexico, Impulsora Agrícola S.A. de C.V.
Mexico, Industrias Vazquez
Spain, Agrovegetal
Switzerland, Syngenta
UK, KBiosciences
USA, Agripro (Syngenta)
USA, Pioneer Hi-Bred Intl.
USA, Monsanto

Non-Governmental Organizations and Farmers Cooperative Organizations (0 funded/14 total)
India, Sathguru
Mexico, Fundacion Produce Sonora A.C.
Mexico, Cd. Obregon, Sonora, AGROASEMEX
Mexico, Cd. Obregon, Sonora, AOASS
Mexico, Sonora, Patronato para la Investigacion y Experimentacion Agricola del Estado de Sonora, AC
Mexico, Cd. Obregon, Sonora, Sistema Producto
Mexico, Ejido Nuevo Leon, B.C., UABC
Mexico, Cd. Obregon, Sonora, UCAC
Mexico, Huatabampo, Sonora, UCACH
Mexico, Cd. Obregon, Sonora, UCAIVYSA
Mexico, Navojoa, Sonora, UCAMAYO
Mexico, Cd. Obregon, Sonora, USPRUSS
Nepal, International Development Enterprises
USA, Hockaday School

Countries hosting WHEAT offices (20 funded/20 total)
Afghanistan, Kabul, Ministry of Agriculture
Bangladesh, Dhaka, Ministry of Agriculture
China, Beijing, Ministry of Agriculture and Chengdu, Sichuan Academy of Agricultural Sciences
Egypt, Cairo, Ministry of Agriculture
Ethiopia, Addis Ababa, Ministry of Agriculture
India, New Delhi, Ministry of Agriculture
Iran, Karaj, Ministry of Agriculture
Kazakhstan, Astana, Ministry of Agriculture
Kenya, Nairobi and Njoro, Ministry of Agriculture
Lebanon, Beirut, Ministry of Agriculture
Mexico, Mexico, Ministry of Agriculture
Morocco, Rabat, Ministry of Agriculture
Nepal, Kathmandu, Ministry of Agriculture
Pakistan, Islamabad, Ministry of Agriculture
Sudan, Khartoum, Ministry of Agriculture
Syria, Aleppo, Ministry of Agriculture
Tunisia, Tunis, Ministry of Agriculture
Turkey, Ankara, Ministry of Agriculture
Uzbekistan, Tashkent, Ministry of Agriculture
Yemen, Sana'a, Ministry of Agriculture

Annex E. Addressing counterfactual and attribution issues in *ex post* impact assessments

When new technologies are made available, some progressive farmers choose to adopt them and expectedly benefit from this adoption. Progressively early individual adoptions result in diffusion of the technology and its benefits in the population, making the nature of the impacts dynamic and fundamentally change over time. The diffusion is fueled by spillovers (e.g. farmer-to-farmer transfer) from adopters to non-adopters and also learning among adopters that enhance the efficiency of use and profitability of the new technology. With adoption at scale, technology diffusion and increased supply of the product may affect prices, create employment opportunities and hence generate higher benefits even to consumers. The benefits of a technology may therefore tend to diffuse in the economy to consumers and workers, while only partially remaining with producers.

The key quantity that impact evaluation studies attempt to estimate is the *average effect* of adoption on outcomes for those who have adopted, known as the average treatment effect on the treated (ATT). Because of the selection effect (the presence of systematic differences between comparison groups in ways that affect both treatment status and the outcomes from treatment), the main challenge is to establish the proper counterfactual group against which to compare adopters (de Janvry et al. 2011).

Various experimental and quasi-experimental approaches can be used to establish statistical comparison groups that account for placement and selection bias in estimating the microeconomic impact of the technology derived from early adopters. The challenge in this case is to find among the non-adopters some good counterfactual that can be validly compared with the adopters. Among the quasi-experimental methods, matching methods based on selection on observables (propensity scores) and difference-in-difference (DID) and instrumental variables (IV) methods have been used widely in recent evaluation studies. When panel data is available, the DD and IV methods do better than the single difference cross sectional methods (e.g. PSM) to estimate the ATT when non-time varying unobservable heterogeneity is important and affects both adoption and outcome variables.

The use of randomized controlled trials (RCTs) eliminates selection bias between treatment and control groups through random assignment. Thus, RCTs are being used increasingly in development programs for their strong counterfactual treatment and high internal validity. While RCTs appeal to many economists and to some donors, they are controversial and criticized by many in the evaluation field. Some concerns relate to high cost and ethics of purposively denying access to control groups which can be ethically problematic in some circumstances. However there is considerable scope for strengthening the internal validity and attribution of estimating the average treatment effect of a technology by using experimental methods as a component of impact assessment (de Janvry et al. 2011; Khandkern et al. 2010)

The presence of spillovers and general equilibrium effects makes it hard to establish counterfactuals, especially for measuring the impact of long term technological change which may involve diffusion at scale that generates price and employment benefits to workers and consumers. In this case, the share of benefits accruing to each set of actors in the economy varies as markets adjust to the effects of the new technology on outputs as well as demand for production inputs. With long term technological change and impact at scale, one faces the challenge of many years, with continuous evolution of the technology, and lack of a proper counterfactual (still using the 'technology' from many years ago) to compare to the current adopters. Rigorous estimation of an impact in this context resorts to the standard econometric techniques that can exploit the progressive and heterogeneous diffusion of the technology over time and space, provided one can identify enough units that can be treated independently (de Janvry et al. 2011). If enough data are available on other exogenous or behavior-independent factors affecting participants and nonparticipants over time, those factors can be exploited to identify impacts when unobserved heterogeneity is not constant. Panel data methods (random and fixed effects) and an instrumental variables panel fixed-effects approach could be implemented (Khandkern et al. 2010).

Another approach for estimating the treatment effect of large scale adoption and impact of technological change is to exploit combined econometric and simulation modeling (economic surplus and computable general equilibrium –CGE) approaches. Because of the extreme difficulty of carrying out a rigorous and credible estimation of long-term aggregate effects of technological change, researchers have resorted to several different types of analyses. One is to focus on smaller units of observation (such as villages) on the presumption that markets are not well integrated and therefore each unit represents a small 'economy'. In this case, econometric analyses of observations over time are presumed to identify the causal effect of an uneven development of technological change. The second type of analysis uses simulation models to extrapolate impacts measured at the micro-level to the level of aggregate effects using simulation models. This approach combines some estimation of microeconomic impact (based on methods outlined above such as RCTs or quasi-experimental approaches) with observed patterns of diffusion and a model for changes in prices and general equilibrium effects, which produces simulated aggregate and long-term effects (de Janvry et al. 2011).

If properly implemented, the use of RCTs for estimating the microeconomic impact of technological change to control for unobserved heterogeneity helps to establish a stronger internal validity for impact assessment while also serving as a good basis for estimating wider impacts at scale when the technology has spread to wider areas, thereby enhancing external validity. While partial equilibrium models (e.g. RCTs) would tell us what the direct effect of such adoption might be on household incomes and poverty, the use of CGE model that build on a valid microeconomic impact analysis allows us to study both the direct effects (i.e., it measures how changes in profitability translate into changes in household income) and indirect (e.g. price and employment) effects of technology adoption at scale.

References

de Janvry, A., Dunstan, A., Sadoulet, E. (2011) Recent advances in impact analysis methods for ex-post impact assessment of agricultural technology: Options for the CGIAR. Report submitted to SPIA, Rome.

Khandkern, S., R., Koolwal, G., B., and Samad, H., A. (2010) Handbook on Impact Evaluation Quantitative Methods and Practices. The World Bank